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NUREG/CR-6751

The Human Performance Evaluation Process: A Resource for Reviewing the Identification and Resolution of Human Performance Problems

Performance, Safety and Health Associates, Inc.

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U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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The Human Performance Evaluation Process: A Resource for Reviewing the Identification and Resolution of Human Performance Problems

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Prepared by
V. Barnes, B. Haagensen[1]

Contributing Author:
J. O'Hara[2]

[1]Performance, Safety and Health Associates, Inc.
P.O. Box 30
Boalsburg, PA 16827

[2]Brookhaven National Laboratory
Energy Sciences and Technology Department
Upton, NY 11973

I. Schoenfeld, E. Trager, NRC Project Managers

Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
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ABSTRACT

The Human Performance Evaluation Process (HPEP) is a resource for U.S. Nuclear Regulatory Commission inspectors to use when reviewing licensee problem identification and resolution programs with regard to human performance. Part I provides a step-by-step process for reviewing licensee effectiveness in identifying, analyzing and resolving human performance problems. Part I also addresses the challenges in identifying and investigating human performance problems, describes three root cause analysis techniques, and discusses characteristics of effective corrective action plans. Part II is comprised of the HPEP Cause Tree and Modules. The Cause Tree is a screening tool for identifying the range of possible causes for a human performance problem. The Modules describe frequently identified causes for human performance problems and provide examples. Part II is intended to support the evaluation of licensee root cause analyses for human performance problems identified in Part I.

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PART I:

THE HUMAN PERFORMANCE REVIEW PROCESS

1 OVERVIEW OF THE HUMAN PERFORMANCE EVALUATION PROCESS (HPEP)

1.1 INTRODUCTION

Reliable human performance is a requirement for safe operations in many settings, including operations of commercial nuclear power and nuclear materials licensees. Among the industries regulated by the U.S. Nuclear Regulatory Commission (NRC), **human error** has played an important role in numerous events. Researchers for the Electric Power Research Institute note:

> Ever since the systematic study of human performance and accidents began, it has been clear that human errors (i.e., inappropriate or inadequate human actions) contribute to a large portion of accidents and incidents. This has been found true for vehicle operation (aircraft, cars, motorcycles, bicycles), for industry (commercial aviation maintenance, manufacturing, chemical processing, mining), and for electric power generation. In nuclear power generation, the portion of events or mishaps attributed at least in part to human error has ranged from 40% to 80%, depending on the study and the specific measures used, but it is consistently reported as having a major role (Gross and Ayres, 1998).

Human errors may play several different roles in an event sequence. An error may

- directly cause an event,
- contribute to an event by setting up the conditions that, in combination with other events or conditions, allowed the event to occur (e.g., leaving a valve open that should be closed),
- make the consequences of an event more severe, or
- delay recovery from an event.

Human errors typically contribute to events rather than directly cause them. In fact, a single human error directly causes very few significant events because most systems that involve nuclear processes are designed to be fault-tolerant; that is, designed to prevent a single human action (or failure to act) from causing an event with important consequences.

More often, a risk-significant event involves several system deficiencies, some of which may have happened long before the event takes place. For example, errors in the original installation of a system may set the stage for another human error to initiate an event months or years later. The value of investigating the human errors involved in an event is to understand what caused them so that **corrective actions** can be developed to minimize the likelihood of recurrence.

It is also important to detect and correct patterns of errors before they result in an event. **Human performance trends** are a pattern of related errors resulting from the same causal factors.

Although most errors that are made day-to-day have no immediate impact on safe operations, an adverse human performance trend may contribute to an overall increase in risk to the public. For example, a pattern of related errors may systematically degrade the reliability of a class of components (e.g., miscalibration errors) or the errors may be committed in the wrong combination of circumstances and cause an event.

In most cases, the causes of errors that occur in an event or as part of a trend (collectively referred to here as **human performance problems**) can be traced to weaknesses in the programs, policies and practices that NRC licensees use to increase the reliability of human performance in their operations. Examples of these programs include training and qualification programs; the fitness-for-duty program; programs to develop and validate procedures; work planning and control processes; overtime policies; and structured methods for communicating important information, such as shift turnover. Programmatic weaknesses are often found to be the root causes of human performance problems.

In the course of implementing NRC Inspection Procedure 71152, Identification and Resolution of Problems, inspectors may be called upon to validate licensees' investigations of events involving human performance problems. For significant conditions adverse to quality, inspectors will evaluate licensees' detection and characterization of human performance problems as well as the effectiveness of licensee root cause analyses and corrective actions. The Human Performance Evaluation Process (HPEP) is intended to help NRC inspectors in performing these tasks.

1.2 OBJECTIVES

The HPEP is not intended to replace existing NRC inspection procedures. The purpose of the HPEP is to support NRC staff reviews of the effectiveness of licensee problem identification and resolution programs in detecting and resolving human performance problems. Methods are presented for evaluating licensee investigations of human performance problems, root cause analyses and corrective actions. It is recognized that the approach described in Part II of the HPEP is different from that used in NRC inspection procedures, such as Inspection Procedure 71841, Human Performance.

1.3 ORGANIZATION

The HPEP is presented in two parts. Part I is a step-by-step process to help a reviewer evaluate a licensee's problem identification, investigation, causal analyses and corrective actions for human performance problems. Part II is comprised of the HPEP Cause Tree and Modules. The modules provide background information on frequently identified causes of human performance problems and specific examples to assist in the evaluation of a licensee's causal analyses.

A glossary of terms and concepts that are central to understanding and applying the review guidance is presented in Appendix A. Terms that are defined in the glossary are presented in bold in the text.

Appendix B presents a bibliography of sources used to develop this document. References are not cited in the text in order to increase the usability of the document.

2 HUMAN PERFORMANCE PROBLEM REVIEW

2.1 OVERVIEW OF THE REVIEW PROCESS

In this section, a systematic method is presented for evaluating the effectiveness of a licensee's identification and resolution program with regard to human performance problems. The HPEP review process is organized as a series of tables that ask the inspector to answer evaluation questions in four areas. These areas are:

- The licensee's identification and characterization of human performance problems (Table 2.1 Problem Identification and Characterization)
- Methods and information used to investigate human performance (Table 2.2 Investigation Methods)
- The analyses used to determine the causes of the human performance problems (Table 2.3 Causal Analyses)
- The likely effectiveness of corrective action plans (Table 2.4 Corrective Actions).

Table 2.5, Summary Review Table, is provided to assist in summarizing the results of the review. Blank tables are presented at the end of this section and in Appendix C for copying.

More detailed background information on each of the evaluation areas is provided in Sections 3-6 of this document, as follows:

- Challenges in identifying human performance problems and the theoretical framework underlying the HPEP are discussed in Section 3.
- Information and detailed guidance regarding appropriate investigation methods for human performance problems are presented in Section 4.
- An overview of root cause analysis is presented in Section 5. Three root cause analysis techniques are also described: events and causal factors analysis, barrier analysis and change analysis.
- Information regarding corrective actions for human performance problems is presented in Section 6. This section discusses alternative methods of correcting human performance problems and determining the appropriate scope of a corrective action plan.

The HPEP Cause Tree and Modules are presented in Part II of this document to assist in answering the questions in Table 2.3, Causal Analyses. This additional information on typical causes of human performance problems is presented because determining the causes for human performance problems is often difficult.

2.2 PROBLEM IDENTIFICATION AND CHARACTERIZATION

The review questions in Table 2.1 (p. 2-9) may be used in evaluating the extent to which licensees appropriately identify and characterize human performance problems. Human performance problems are sometimes difficult to identify in the documents that describe problems at licensee facilities or may not be identified at all. Licensee documentation may focus on system or equipment performance without discussion of the human actions and decisions that contributed to the event or condition.

There are a number of reasons that human performance problems may not be well documented in either internal licensee problem reports or in reports to the NRC. For example, human errors may not be reported and documented as such to avoid embarrassment to personnel or possible disciplinary action. A more complete discussion of the challenges in identifying human performance problems is presented in Section 3.

For some problems that the licensee has identified, human actions and decisions may not be important contributors to the problem. In others, human behavior may have been central to creating the problem, and an understanding of the nature and causes of the behavior was necessary to develop effective corrective actions. In the latter case, it is important that the human performance problem was characterized in sufficient detail to support problem resolution.

If the licensee did not identify the human performance problem(s) in the documents available for review, it may be necessary to request additional documents or to interview licensee personnel. Often, the human performance problem(s) in an event, for example, were identified and investigated, but the information may not have been included in a formal report.

2.3 INVESTIGATION METHODS

The review questions in Table 2.2 (p. 2-10) may be used to guide the evaluation of a licensee's investigation of a human performance problem. A thorough and systematic investigation is necessary to provide the information needed to perform causal analyses and develop effective corrective actions.

In general, the extent to which licensee personnel will investigate a human performance problem depends upon the perceived significance of the problem. For example, an error that caused a reportable event will likely receive more attention than an error that resulted in an event that was not reportable. Many licensees have established criteria for determining the types of problems that must be investigated and the degree of thoroughness required in the investigation. These criteria may include risk, cost, or regulatory implications, for example. If a human performance problem falls below the licensee's threshold for conducting an investigation and the inspector agrees with the licensee's determination, many of the questions in Table 2.2 will be marked as NA for the problem.

A discussion of methods for investigating human performance problems can be found in Section 4.

2.4 CAUSAL ANALYSES

The review questions in Table 2.3 (p. 2-12) may be used in evaluating the licensee's causal analyses of human performance problems. The purpose of analyzing the causes of human performance problems is to guide the development of effective corrective actions. Standard **root cause analysis** techniques, such as events and causal factors charting and analysis, change analysis and barrier analysis, are resource-intensive and time-consuming to apply, but yield reliable and useful results when performed properly. Use of the standard techniques may not always be warranted, however, and licensees apply these techniques only to the more significant problems. When standard root cause analysis techniques are used, more than one cause is typically identified for a human performance problem. An overview of root cause analysis, and a discussion of the different types of causes that will be identified by using root cause analysis techniques, can be found in Section 5.

More detailed information about frequently identified causes of human performance problems is presented in the HPEP Cause Modules in Part II. The HPEP Cause Tree and Modules are intended to assist inspectors in verifying the causal factors a licensee has identified as an aid in answering the questions in Table 2.3.

2.5 CORRECTIVE ACTIONS

The review questions in Table 2.4 (p. 2-14) may be used in evaluating the licensee's corrective actions for human performance problems. An effective corrective action for a human performance problem is one that will decrease the likelihood that it, and similar problems, will happen again. In an ideal world, an effective corrective action would prevent recurrence of the human performance problem. As discussed in Section 3, however, the causes of human behavior are difficult to identify and, as a result, measures to improve human performance often yield inconsistent results.

Developing effective corrective actions typically requires a thorough root cause analysis and an understanding of available methods for enhancing human performance. Depending upon the significance and scope of the cause(s) identified, corrective action plans may vary in scope from correcting a single cause, such as a missing tag on a valve, to a general organizational improvement plan. As a minimum, corrective actions must address each of the causal factors identified from the investigation.

Corrective action plans that have an appropriate scope still may be ineffective, however. Corrective action plans may be ineffective because, for example, the steps for achieving the plan's objectives were not defined in detail; responsibility was not assigned to specific individuals for accomplishing the actions; or measures for determining the success of the corrective actions were not defined or used to refine the plan when necessary. Other management initiatives and events may arise that take precedence over implementing the corrective actions. Without a method for monitoring the on-going effectiveness of the corrective action plan, human performance problems may reoccur.

More detailed background information about corrective action plans can be found in Section 6.

2.6 USING THE REVIEW TABLES

Follow these steps to use the review tables:

1. Assemble the reports that describe the human performance problems to be evaluated. These may consist of Licensee Event Reports, self-assessments, problem reports entered into a licensee's corrective action tracking system(s), licensee responses to inspection findings, or others. Request that the licensee also provide any related background or supporting documentation that may contain more information than what is available in the reports.

2. Identify each human error or trend that is described in the documents and develop a brief, shorthand description of the human performance problem. Focus on describing the human behavior or action, to the extent that information is available. For example, "procedure step skipped," "alarm disabled," "jumper not removed," and so on. Record the brief description in the top row of each table, along with the date it occurred, if that information is available. (If you will be reviewing multiple human performance problems, make additional copies of the tables. Space is provided on each table to review two problems.)

3. In the row labeled "Document Identifier" at the top of Table 2.1, you may also want to record information about the source document in which you found the human performance problem discussed for later reference.

4. Begin the review of each human performance problem with Table 2.1 and continue through Table 2.4. Answer the questions in all of the tables for each problem. If a question is not applicable to the problem, mark it as NA. Space is provided in each table for recording notes.

5. When you have completed answering the questions on the page, count up and record the total number of Yes answers you circled and the total number of NA answers you circled on that page. Record these totals in the spaces provided in the lower right-hand corner of the page. The questions in each table are designed so that a Yes answer suggests problem identification and resolution program effectiveness. There is no threshold percentage of Yes answers that would show that a licensee's problem identification and resolution program was ineffective with regard to human performance. However, these percentages provide an indication of program sensitivity to human performance problems.

6. When you have completed Tables 2.1-2.4 for each human performance problem under review, summarize the results of your evaluations in Table 2.5. By following the procedure described below, calculate the percentage of Yes answers you circled to the applicable evaluation questions in each area addressed by the tables. Figure 2.1 shows an example of Table 2.5 that has been completed for a hypothetical inspection.

a. Record the total number of human performance problems you reviewed in the space provided at the top left of the table.
b. Multiply the number of problems you reviewed by the number of questions in each table (the latter number is provided in the summary table).
c. Add up the total number of Yes answers you circled in each table and record those totals in Row C. For example, if you used six copies of Table 2.1 (to review twelve human performance problems), you would add up the Yes answers on all of the six pages to arrive at the total number of Yes answers you circled in Table 2.1. Record this total in Row C in the column titled "2.1 Problem Identification and Characterization" on Table 2.5, the "Summary Review Table."
d. Add up the total number of NA answers you circled in each table and record those totals in Row D.
e. Subtract the total number of NA answers (Row D) from the total calculated in Row B. The difference represents the number of applicable questions that could have been answered Yes.
f. Divide the number of Yes answers in each table (as recorded in Row C) by the number of applicable questions that could have been answered Yes (as recorded in Row E).
g. Multiply the result in Row F by 100 to arrive at the percentage of Yes answers you circled out of the total number of applicable questions that could have been answered Yes.
h. Adding up your answers to each question in Tables 2.1-2.4 may also be useful in developing insights regarding any specific areas of weakness in the licensee's problem identification and resolution program with regard to human performance. For example, question 2.2.3 in Table 2.2 asks, " Did the licensee validate the information gathered about the problem by seeking information from more than one source?" If you find that you circled No for 11 out of 12 problems reviewed, your answers may suggest that further assessment of the licensee's investigation methods is warranted. Copies of the tables may also be used to record the tallies for each question.

2.7 ASSESSING RISK IMPACT

There are a number of methods available for assessing the risk importance of the human performance problems reviewed. The problem identification reports that are reviewed may be screened prior to the HPEP evaluation to ensure that only risk-important events or trends are evaluated. Or, as the HPEP evaluation progresses, the inspector may identify human performance problems that should be evaluated for risk-significance. Guidance for assessing the risk impact of weaknesses in the licensee's problem identification and resolution processes with regard to human performance problems may also be consulted.

2.8 INCORPORATING HPEP FINDINGS IN AN INSPECTION REPORT

The results of an HPEP review, taken together with other information from inspection activities, should assist NRC personnel in drawing conclusions regarding the effectiveness of a licensee's problem identification and resolution program for human performance. For example, if an HPEP

review indicated that a licensee identified and appropriately characterized the human performance problems in only 10% of the issues reviewed (as indicated by the percentage of Yes answers calculated in Row G of Table 2.5), inspectors may question the sensitivity of the program to human performance problems. Or, if a low percentage of Yes answers were given to the questions in Table 2.3 regarding the licensee's causal analyses, inspectors may question the likely effectiveness of corrective actions based upon those analyses. Taken together with additional information that shows a pattern of undetected human performance trends, a low percentage of Yes answers to the HPEP review questions could support a finding that the licensee's program is weak in the identification and resolution of human performance problems.

Table 2.5 Summary Review Table

A. Number of human performance problems reviewed = 10	Tables			
	2.1 Problem Identification and Characterization	**2.2 Investigation Methods**	**2.3 Causal Analyses**	**2.4 Corrective Actions**
Number of questions in each table	6	10	13	12
B. Multiply the number of questions in each table by the total number of problems reviewed	6 X 10=(B)60	10 X 10=(B)100	13 X 10=(B)130	12 X 10=(B)120
C. Record the total number of Yes answers circled from each table	(C) = 40	(C) = 65	(C) = 110	(C) = 87
D. Record the total number of NA answers circled from each table	(D) = 7	(D) = 5	(D) = 0	(D) = 3
E. Subtract the total from Row D from the total in Row B	(B)60 - (D)7=(E)53	(B)100 - (D)5=(E)95	(B)130 - (D)0=(E)130	(B)120 - (D)3=(E)127
F. Divide the answer in Row C by the answer in Row E	(C)40 /(E)53=(F).75	(C)65 /(E)95=(F).68	(C)110 /(E)130=(F).85	(C)87/ (E)127=(F).69
G. Multiply the answer in Row F by 100 to obtain the percentage of Yes answers	(F).75 X 100 = 75%	(F).68 X 100 = 68%	(F).85X 100 = 85%	(F).69 X 100 = 69%

Figure 2.1 An Example of Table 2.5 Completed for a Hypothetical Inspection

HPEP REVIEW TABLES

Table 2.1 Problem Identification and Characterization

Document Identifier:		Problem Number: __		Problem Number: __	
Question Number	**Brief description of the problem and date(s) of occurrence:**				
2.1.1	Was the human performance problem identified?	Yes No NA	Notes:	Yes No NA	Notes:
2.1.2	If not, was the human performance problem tangential to understanding and resolving the issue under review?	Yes No NA		Yes No NA	
2.1.3	Were the individuals involved in the problem identified (by job role)?	Yes No NA		Yes No NA	
2.1.4	Were the actions and decisions or failures to act that comprised the problem described?	Yes No NA		Yes No NA	
2.1.5	Were precursor errors or earlier evidence of a developing trend identified?	Yes No NA		Yes No NA	
2.1.6	Was the problem described in enough detail to support causal analyses and the development of corrective actions?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.2 Investigation Methods

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.2.1	Was the extent of the investigation consistent with the importance of the problem?	Yes No NA	Notes:	Yes No NA	Notes:
2.2.2	Were licensee criteria for determining which issues require an investigation appropriately applied to this problem?	Yes No NA		Yes No NA	
2.2.3	Did the licensee validate the information gathered about the problem by seeking information from more than one source?	Yes No NA		Yes No NA	
2.2.4	Did the licensee seek the appropriate type(s) of evidence for investigating the problem?	Yes No NA		Yes No NA	
2.2.5	Did the licensee gather enough information to understand the sequence of events and conditions leading up to the problem?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.2 Investigation Methods (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.2.6	Did the licensee check plant records to identify other problems that occurred during the same work activity?	Yes No NA	Notes:	Yes No NA	Notes:
2.2.7	Did the licensee identify the programs that applied to the job(s) during which the human performance problem arose?	Yes No NA		Yes No NA	
2.2.8	If the licensee found weaknesses in the applicable programs, were the weaknesses investigated in sufficient detail to understand their scope and likely effects, if not corrected?	Yes No NA		Yes No NA	
2.2.9	Were the licensee's conclusions clearly supported by the results of the investigation?	Yes No NA		Yes No NA	
2.2.10	Was there a basis documented for stopping the investigation?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.3 Causal Analyses

Question Number	Problem description:	Problem number: __		Problem Number: __	
2.3.1	Were causal factors identified for this human performance problem?	Yes No NA	Notes:	Yes No NA	Notes:
2.3.2	Was more than one causal factor identified for the problem?	Yes No NA		Yes No NA	
2.3.3	Was the type of causal analysis of this problem consistent with its importance?	Yes No NA		Yes No NA	
2.3.4	Was there enough information provided to verify the accuracy of the causal factors identified?	Yes No NA		Yes No NA	
2.3.5	Were several possible causes for the problem investigated?	Yes No NA		Yes No NA	
2.3.6	Did the evidence support the licensee's choice of causes?	Yes No NA		Yes No NA	
2.3.7	Were the bases for rejecting possible causes for the problem documented?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.3 Causal Analyses (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.3.8	**Did the licensee analyze programmatic weaknesses to determine if they could account for more than one human performance problem?**	Yes No NA	Notes:	Yes No NA	**Notes:**
2.3.9	**Did the licensee perform and document a root cause analysis using systematic root cause analysis techniques?**	Yes No NA		Yes No NA	
2.3.10	**Was more than one root cause analysis technique used?**	Yes No NA		Yes No NA	
2.3.11	**Was the rationale for terminating the root cause analysis sufficient and documented?**	Yes No NA		Yes No NA	
2.3.12	**Were the root causes identified under management control?**	Yes No NA		Yes No NA	
2.3.13	**If corrected, would the causes identified reduce the likelihood of the same and similar problems from happening again?**	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.4 Corrective Actions

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.4.1	Were corrective actions for the human performance problem identified?	Yes No NA	Notes:	Yes No NA	Notes:
2.4.2	Were the corrective actions effective, or appear likely to be effective, even if no causal analysis was performed and/or documented?	Yes No NA		Yes No NA	
2.4.3	If a causal analysis was performed, were the links between the causal factors and the corrective actions clear?	Yes No NA		Yes No NA	
2.4.4	Was there a corrective action for every causal factor? (a one-to-one correspondence is not required)	Yes No NA		Yes No NA	
2.4.5	Was the scope of the corrective action plan appropriate?	Yes No NA		Yes No NA	
2.4.6	Were the desired condition(s) that the corrective actions are intended to create clearly described?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.4 Corrective Actions (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.4.7	Did the licensee define measurable objectives to be achieved from the corrective actions?	Yes No NA	Notes:	Yes No NA	Notes:
2.4.8	Did the licensee define evaluation and acceptance criteria for assessing corrective action effectiveness?	Yes No NA		Yes No NA	
2.4.9	Did the licensee define an implementation process for the corrective actions and specific performance indicators for evaluating success?	Yes No NA		Yes No NA	
2.4.10	Did the licensee assign responsibility to specific, qualified individuals for implementing the corrective actions?	Yes No NA		Yes No NA	
2.4.11	Did the licensee develop a plan for on-going monitoring of continued acceptable performance?	Yes No NA		Yes No NA	
2.4.12	Did the licensee review the corrective actions before implementation to ensure that they will not cause unintended negative consequences?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.5 Summary Review Table

A. Number of human performance problems reviewed = ____	Tables			
	2.1 Problem Identification and Characterization	**2.2 Investigation Methods**	**2.3 Causal Analyses**	**2.4 Corrective Actions**
Number of questions in each table	6	10	13	12
B. Multiply the number of questions in each table by the total number of problems reviewed	6 X ___=(B)____	10 X ___=(B)____	13 X ___=(B)____	12 X ___=(B)____
C. Record the total number of Yes answers circled from each table	(C) = ____	(C) = ____	(C) = ____	(C) = ____
D. Record the total number of NA answers circled from each table	(D) = ____	(D) = ____	(D) = ____	(D) = ____
E. Subtract the total in Row D from the total in Row B	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____
F. Divide the answer in Row C by the answer in Row E	(C)____/(E) ____=(F)____	(C)____/(E) ____=(F)____	(C)____/(E)____=(F)____	(C)____/ (E)____=(F)____
G. Multiply the answer in Row F by 100 to obtain the percentage of Yes answers circled in each review table	(F)____X 100 = ____%	(F)____X 100 = ____%	(F)____X 100 = ____%	(F)____X 100 = ____%
Notes:				

3 IDENTIFYING HUMAN PERFORMANCE PROBLEMS AND THEIR CAUSES

3.1 INTRODUCTION

Identifying human performance problems and their causes is often difficult. Further, the simple identification of "human error" as a root or contributing cause of events provides little information about how to prevent similar problems from recurring. Recognizing human performance problems when they occur and accurately identifying their causes are necessary first steps to developing effective corrective actions.

In this section, the term, "**human error**," is discussed and the challenges to identifying human performance problems are discussed. Common difficulties in identifying the causes of error are also discussed. Finally, the framework for investigating human errors that underlies the design of the HPEP is presented.

3.2 CHALLENGES IN IDENTIFYING HUMAN PERFORMANCE PROBLEMS

The term, "human error," refers to an interaction between human behavior and the context in which it occurs.[1] The concept of an interaction is important because it is the context in which a human action takes place that determines whether or not it is an error. In most cases, a particular human action only becomes an "error" when it deviates from what was planned or expected in a given task environment. This definition of error is important because it directs attention both to the behavior and to the characteristics of the task environment that allowed the behavior to cause or contribute to an event.

The human behaviors of greatest concern in a nuclear power plant are those in which personnel interact with plant equipment and systems (i.e., human-system interactions), such as manipulating valves, operating controls, placing or removing jumpers, locating and reading gauges, or making and implementing decisions. Human-system interactions affect plant performance.

Human performance trends, defined as a pattern of related errors resulting from the same causal factors, may be difficult to identify for several reasons. First, humans commit errors

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[1] The term, "human error," has become somewhat controversial. Some practitioners and researchers have argued that it inappropriately focuses attention on workers as the cause of an event and carries a connotation of blame (NUREG-1624, 2000; Reason, 1997). The term is used in this document, however, because "error" accurately implies that the very large majority of actions (or failures to act) that cause or contribute to events are unintentional. For blame to accrue to an individual worker, it would be necessary to establish that the worker had both knowledge of the correct actions to take in the given context and took the incorrect actions with intent (i.e., despite the knowledge that the actions were proscribed). If both knowledge and intent were established, but the intent did not involve causing harm, then the more accurate term for the worker's behavior would be a "violation." If harm was intended, which we are certain is rarely the case, then the more accurate term would be "sabotage." Both violations and sabotage fall outside the scope of this document.

relatively frequently but the errors often are not detected and reported as such. Most are not detected for two primary reasons: (1) they have no impact on equipment or system performance, or (2) they are caught and corrected before they have an impact. Errors are so common, in fact, that people often do not notice an error has been committed unless it results in observable consequences, such as degraded equipment, injuries, or equipment failures.

Second, personnel are often reluctant to report their own or co-workers' errors for many different reasons. These may include the desire to avoid embarrassment or the potential for disciplinary action; "chilling effects" from management that discourage workers from reporting problems; a fear of retaliation or social ostracism from peers; the simple burden of filling out paperwork; or there may be no systematic and impersonal method available to report errors and their causes. As a result, a pattern of repeated errors may not be detected until they have a noticeable impact on hardware performance. An accepted practice of deviating from the steps in a poorly written procedure, rather than ensuring that the procedure is revised, is an example of an error that may not be reported, but could result in adverse consequences if, for example, the deviations had undetected effects on equipment, such as accelerated aging.

Third, some licensee's corrective action item tracking systems may not be designed to support the aggregation of human performance data to identify trends. In some cases, problems are coded and tracked by the system, component or part, and human errors that occurred to cause the problem may be buried in the problem descriptions and not coded in a manner that is retrievable for analysis. As a result, different errors that result from the same cause may not be identified as symptoms of an underlying problem.

Finally, management and regulators may also affect the human performance information that is reported and tracked. For example, some managers may edit or influence the writing of problem reports to ensure that their departments are not blamed for the problems or to address economic considerations. Regulatory interest in some types of human performance problems may influence the types of problems that are reported and how they are characterized. The results might be that some problems are under-reported while others may be over-reported.

A number of classification schemes have been developed to categorize human errors into different types. For example, Kirwan (1994) identifies four types of errors, including (1) errors of commission, in which incorrect actions were taken, (2) errors of omission, in which required actions were not taken, (3) extraneous acts, in which an action that was not required was taken, and (4) missed error-recovery opportunities, comprised of actions which could have corrected previous errors. Other schemes divide errors into motor (e.g., a slip) and cognitive (e.g., a mental lapse) categories that may be further divided into subtypes.

Error classification schemes that focus on behaviors provide a language for describing the different ways in which human behavior in a nuclear licensee's workplace can go wrong. But, as will be discussed below, they are not particularly useful for understanding the causes of errors that lead to events or to on-going human performance problems.

3.3 CHALLENGES IN IDENTIFYING THE CAUSES OF ERRORS

Establishing the causes of errors is necessary to detect and correct human performance problems, but is often more difficult than establishing the causes for hardware failures. The challenge arises from the flexibility and adaptability of human behavior as well as from the post hoc nature of problem or event investigations.

There are few simple, one-to-one relationships between causal factors and specific human errors. For example, a single causal factor, such as fatigue, may cause a variety of different types of errors, such as skipping a step in a procedure, dropping tools, performing maintenance on the wrong valve or failing to detect a sudden change in temperature or pressure on a gauge. Further, humans are highly adaptable and the presence of a potential causal factor does not guarantee that it will cause an error to be committed. Even a deeply fatigued person may be able to sustain high levels of accurate performance in some circumstances, such as in combat or the operating room. Although human factors research provides rules-of-thumb for designing human-system interfaces to reduce the likelihood of errors, and guidelines for the design of tasks and organizations, the person who is investigating an error cannot be sure that the research results apply to the specific situation under investigation.

Establishing causes for human error in an event sequence can be further complicated by weaknesses in the evidence available. For example, although interview data yield reliable information about some **lines of inquiry**, people are notably limited in their ability to know what has influenced their behavior. The social psychological research literature provides numerous examples of how people create explanations for their decisions and actions that bear little or no relationship to what can be objectively demonstrated to have caused them to behave in a particular way. In addition, interview data are subject to various predictable biases and memory distortions that reduce their reliability. For example, some research has shown that the accuracy of people's memories for events decreases by about 50% within two days after the event occurred. Moreover, in contrast to the equipment or materials involved in an event, licensee investigation personnel or NRC inspectors typically do not have the option of sending the humans involved off to the laboratory for additional testing to confirm a causal hypothesis.

The consequence of the lack of a one-to-one correspondence between different types of errors and specific causes is that there is no reliable road map to guide the identification of an error's causes. Any single error may be caused by a variety of factors, and the "true" cause of the error may be unknowable after the fact. Of course, there are cases in which an error's cause can be determined unambiguously. For example, if a procedure step provides an incorrect instruction, personnel report that they followed the step, and the consequences of their actions are consistent with what should have occurred from following the incorrect step, the investigator can be fairly confident that the "true" cause of the error was in the procedure. However, those cases are rare.

Identifying causes for human error is further complicated by many possible sources of bias or limitations in the investigation process itself. The choice of potential causes to investigate for a human error may be influenced, for example, by the investigator's greater knowledge of and comfort level with some causal factors over others as well as by a lack of knowledge in some

areas. Or, the investigation and selection of causal factors may be influenced by the anticipated costs of implementing subsequent corrective actions; institutional biases and mindsets; the time and resources available to conduct the investigation; the investigators' perceptions of what will be acceptable to management; and, sometimes, communications from management regarding acceptable or unacceptable lines of inquiry to pursue and the "right" answers to the investigations' questions.

Inherent biases in how humans process information and come to conclusions about causes may also affect an investigation. For example, research into the event investigation process identified the following ways in which human information-processing biases can affect investigations:

- There is a general tendency to start an investigation with a few ideas about possible causes, and then restrict the investigation to seeking information related to those causes. It is also common to end the investigation before alternative causes have been fully explored.
- People are subject to what has been termed the "confirmation bias," in which they only seek out information that is consistent with an explanation and ignore disconfirming evidence.
- Investigators may base their ideas of possible causes on the most immediately available and visible information and neglect information that is less obvious.
- There is a general human tendency to attribute the cause of an event to the dispositions, motivations or traits of persons rather than to situational factors, so the characteristics of the "actors" involved in an event may be given more weight as causal factors than the characteristics of the work environment.

Because the task of conclusively identifying the cause(s) for an error in an event sequence is so difficult, a comprehensive and systematic approach to investigating human errors is necessary. The barrier analysis framework described below is an approach to investigating human error that has been shown to be useful in practice and to lead to reliable results.

3.4 A BARRIER ANALYSIS FRAMEWORK FOR INVESTIGATING HUMAN ERRORS

The fact that human performance is fallible is one of the bases for the "defense-in-depth" approach to nuclear power plant operations in which multiple barriers to human error are implemented. Research and industry experience have identified both the most common causes of human error and the barriers to error that are effective in addressing these common causes. Those responsible for safe operations implement programs, policies and processes to ensure that these barriers are in-place and functioning, commensurate with the risks posed by the activities involved.

The barriers can be grouped into four basic categories, as follows:

- **Personnel** attributes required for successful task performance, including fitness for duty, knowledge and skills, and attention and motivation

- The **resources** provided to support task performance, such as complete, technically accurate and usable procedures, accurate and complete reference documentation, appropriate tools and equipment, supervision and the appropriate number of staff to accomplish the work
- A **physical work environment** compatible with human capabilities, including the design of human-system interfaces and appropriate controls on environmental factors, such as noise, vibration, and temperature
- An **organizational work environment** that facilitates task performance, including effective verbal and written communications, inter-group and intra-group coordination, an established safety culture, and planning and scheduling of work activities.

When these barriers are in-place and functioning, plant operations are controlled and the likelihood of errors is reduced.

Missing barriers, such as the failure to hold a pre-job briefing for important work on a safety system, or deficiencies in existing barriers, such as a poorly designed display, are often found to be the direct causes of errors. Direct causes of errors are also known as **performance-shaping factors**.

Once an error has been identified and characterized, the initial lines of inquiry into the cause(s) of the error determine what barriers to the error existed and how they failed, and what barriers could have been implemented to prevent the error from occurring, but were missing. The HPEP Cause Modules in Part II (e.g., Procedures, Communications, Supervision) represent the most common barriers implemented at plants to prevent errors. The modules also include examples of the types of direct causes that lead to errors when the barriers fail or are missing.

3.5 ANALYZING THE PROGRAMS THAT CREATE AND MAINTAIN BARRIERS

Although the identification of missing or failed barriers to human error is more useful than simply identifying "human error" as one of an event's causes, stopping the investigation at this level may not provide sufficient information to develop effective corrective actions. When failed or missing barriers to human error are encountered, it is also important to determine whether the failed or missing barriers represent isolated conditions or are symptoms of underlying flaws in the plant programs intended to ensure that the barriers are in-place and effective.

The **root cause** of an error is often found in programmatic weaknesses. **Programs** are comprised of policies (both formal and informal), organizational processes and procedures that define management expectations for how work is to be performed. Some are solely focused on ensuring safe operations (e.g., the ALARA program or the process for developing emergency operating procedures), while others perform a dual role (e.g., human resources and training programs) or have little direct impact on safety (e.g., the accounting system). If there is a flaw in one of the programs responsible for maintaining safe operations, that flaw will create conditions that may not only allow the error under investigation to reoccur, but may represent a vulnerability to additional events caused by the same programmatic flaw. Programmatic weaknesses are often found to be the cause of human performance trends.

As a simple example, an incorrect step in a procedure that is found to have caused an error may represent an isolated problem in a single procedure. Or, there may be a weakness in the program responsible for developing and maintaining procedures that allowed not only the one incorrect step to be published, but was ineffective in ensuring that procedures overall were technically accurate. If the investigation were to stop with the identification of the single incorrect step, and a corrective action was taken to fix that one step in the single procedure, the underlying flaw in the procedures program would not be detected. The consequence of failing to detect and correct the programmatic flaw would be that other inaccuracies in procedures would remain. Further, any new procedures that were developed under the same program could also include technical inaccuracies, thus setting the stage for further errors that could result in future hardware failures and other events.

Tracing the root causes of human error to the programmatic level can be resource intensive, however. Licensee problem identification and resolution programs may not require this type of extensive investigation and analysis until a human error is implicated in a significant problem or event, although definitions of "significance" vary among licensees. Databases that allow the tracking of human errors and their direct causes may pinpoint an emerging human performance trend, however, and could also lead to an investigation of programmatic causes. For this reason, the HPEP includes guidance for assessing a licensee's investigation of programmatic weaknesses that may be causing an adverse human performance trend or that played a causal or contributory role in a significant event.

3.6 SUMMARY

Figure 3-1 illustrates the HPEP framework described in this section. A hypothetical event sequence is shown across the bottom of the figure. Possible direct causes of the human error (barriers that failed or were missing) are shown above the event sequence. Possible programmatic causes that may have been responsible for the barrier failure are shown above the direct causes, demonstrating the loss of operational control that is evident from a human performance problem or significant event. In this hypothetical event, a person who was not qualified to perform the task committed the error, and both the training and work control programs were implicated as root causes.

The HPEP, then, may be used when evaluating a licensee's problem identification and resolution program to determine whether it (1) is effective in identifying the causes of human performance problems that play a causal or contributory role in significant events, and (2) results in corrective actions that target the causes of the problem(s) and result in effective problem resolution.

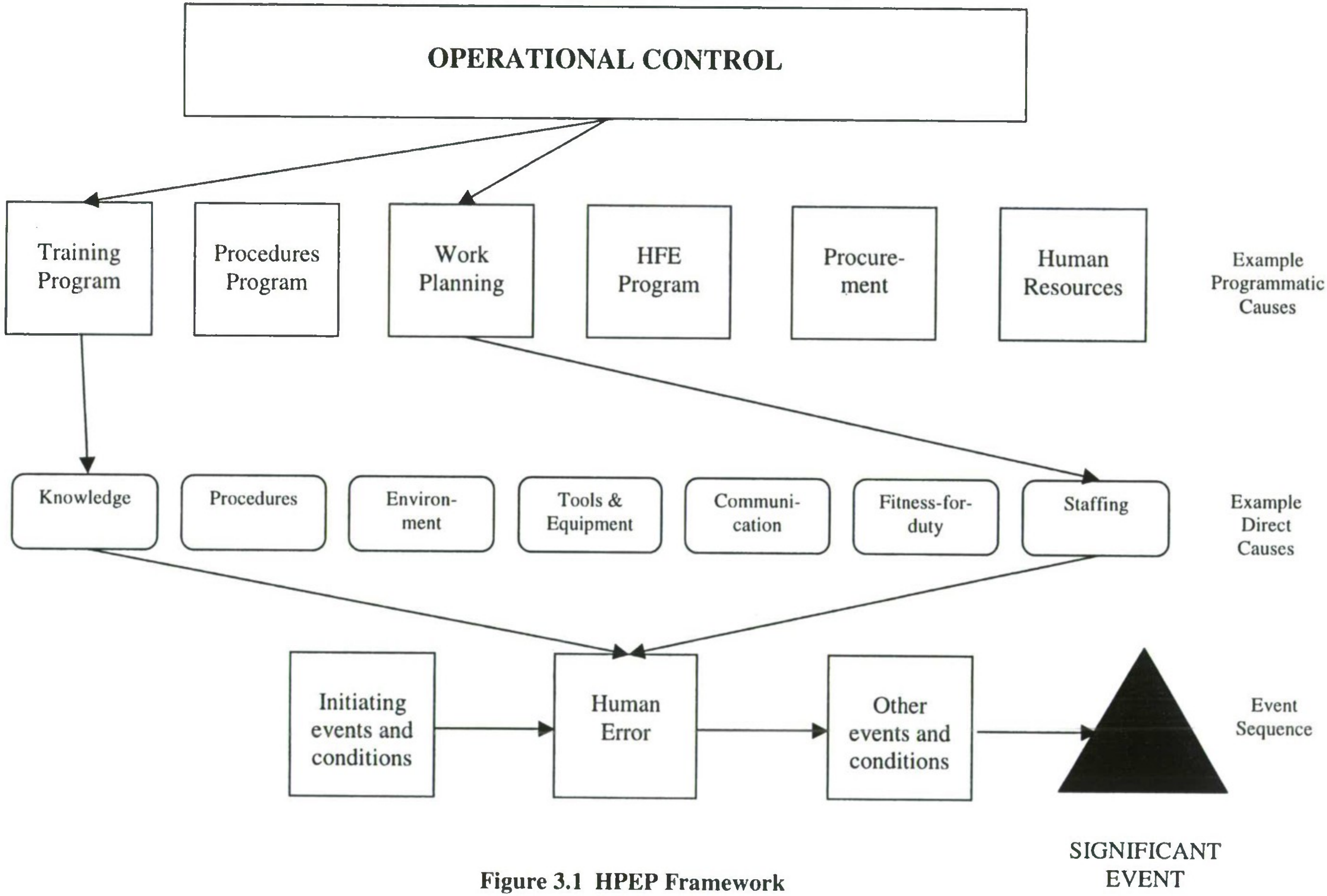


Figure 3.1 HPEP Framework

4 INVESTIGATION METHODS FOR HUMAN PERFORMANCE

4.1 INTRODUCTION

The purpose of investigating human performance problems is to gather the information necessary to identify their causes and develop effective corrective actions. An investigation should establish the "Who, What, When, Where and How?" of the human performance issue. The causal analysis of the information gathered in the investigation establishes the "Why."

In general, the thoroughness with which an error or a human performance problem will be investigated and analyzed depends upon the perceived significance (e.g., safety, potential economic impact) of the event sequence in which the error occurred or the potential for harm that an adverse human performance trend presents. In addition, the role of the error in an event sequence will also influence the extent to which an error is investigated. For example, an error that was the root cause of an event will likely receive more attention than an error that only contributed to the event.

Although licensees will not thoroughly investigate every human performance problem that arises, a systematic investigation of significant problems provides the basis for developing corrective actions to decrease the likelihood of recurrence. The investigation should be systematic to overcome the many challenges to investigating human performance that were discussed in Section 3. A **systematic investigation** process assures that the evidence gathered is complete, valid and reliable. **Evidence validity** refers to the accuracy of the information. **Evidence reliability** refers to whether or not different investigators would find the same information and reach the same conclusions from it. A **complete investigation** identifies the direct, contributing and root causes of the human performance problem so that corrective actions can be developed to minimize recurrence of the same and similar problems. In this section, methods for systematically investigating human performance problems are presented.

4.2 LINES OF INQUIRY

At the beginning of an investigation, investigators focus is on establishing the basic facts surrounding the human performance problem. As the investigation progresses, the lines of inquiry expand to investigate possible causes for the human performance problem and the scope of any problems that are identified.

The initial lines of inquiry in an investigation help characterize the human performance problem. Questions to be answered may include:

- What were the specific actions (or failures to act) that occurred in the event or that comprise the human performance trend?
- What were the conditions under which the actions occurred?
- What work activities, if any, were going on at the time of the error, or that are linked to

the human performance problem?
- What systems or equipment were involved or affected by the actions?
- When and where did the problem occur?
- Who was involved in the work activity and who was supervising?

Developing an event chronology (i.e., a timeline), or an events and causal factors chart, organizes the information gathered and is useful for showing gaps and conflicts in the information that has been collected. **Events and causal factors charting** is discussed in Section 5.

At times, the information required to develop the event chronology leads rapidly to identification of the direct cause of the human error under investigation. For example, the evidence may show that personnel were working in a very noisy environment, wearing hearing protection, and were unable to communicate effectively -- with the result that a communication error occurred. The noisy environment would be the direct cause of the error, in this case.

At other times, the direct cause of the error will not be obvious and more investigation and analysis may be required. Direct causes that are commonly implicated in human performance issues are described in detail in the HPEP Cause Modules in Part II of this document. The Cause Modules may suggest possible lines of inquiry to follow to establish the direct cause of an error. In addition, special tests or analyses may be required. For example, interview data may suggest that the worker who committed the error had been drinking. A blood or breath sample, if available, may be necessary to determine the validity of the interview data and to assess the likelihood that the worker was impaired.

Once the basic facts surrounding the human performance problem have been established, the lines of inquiry expand to begin identifying root and contributing causes for the error. The investigator will analyze the events and conditions leading up to the error and may use standard causal analysis techniques, such as those discussed in Section 5, to identify possible causal factors. **Programmatic causes** are investigated to determine whether a deficiency in a program, policy or practices for managing work activities at a site allowed barriers to error, established by management, to fail. As discussed in Section 3, barriers may fail because they are missing altogether or there is a weakness in how they are implemented.

The **extent of the conditions** that caused the human performance problem is also investigated. The investigator gathers evidence to determine whether the problem has occurred before, how frequently, and whether the conditions that led to this problem could cause other, similar human performance problems if not corrected. Further, the potential consequences of a recurrence of this error under different circumstances should also be evaluated.

For an error that was directly caused by a miscommunication in a noisy work environment, the lines of inquiry to identify programmatic causes and the extent of the conditions that caused the communication error might include: "What were the communication practices, if any, that personnel were trained to use in noisy environments? Did they follow those practices? If not, why not? Were there additional communication practices or devices that would have allowed the

operators to communicate more effectively in the noisy work environment? How many times in the past year have communication errors occurred in this and other noisy environments? Are there circumstances in which an inability to communicate could increase plant risk to unacceptable levels?"

For an error that was directly caused by fatigue from excessive hours worked over several months, the investigator could ask, "What are the work scheduling and overtime practices at this site? How many times in the past year have hours in excess of administrative limits been approved and for how many workers? How many extra work hours were approved for individuals, for certain job positions, within departments? Is there any evidence that error rates increased during the periods in which other personnel were working excess hours? What kinds of tasks were they performing and could errors on those tasks increase plant risk to unacceptable levels?"

The process of establishing the event chronology and gathering the information needed for conducting the causal analyses and to identify the needed corrective actions is described sequentially here. In most investigations, however, the investigation process is iterative. That is, the answers to one set of questions generate new questions for which information must be gathered. In general, the more thorough the investigation, the more likely that the causal analyses will identify the correct causal factors for the problem and that the corrective actions will be effective.

4.3 COLLECTING EVIDENCE

The evidence that can be used to investigate human performance problems falls into three general types. These are defined here as physical evidence, documentary evidence and human evidence. A thorough discussion of evidence collection and preservation methods is outside the scope of this document. Some of the methods for and challenges in collecting and preserving evidence are discussed here, however, to facilitate review of the licensee's investigation.

Physical evidence is any matter (e.g., solids, liquids, gases) related to the error or human performance problem, such as equipment, parts, debris, contaminated water, hardware or tools. Physical evidence may be used to establish the state or condition of equipment and the work environment prior to an event as well as to determine what happened in the course of the event. For example, examination of the personal protective equipment worn by the individuals involved may show that their ability to see through a faceplate or to make fine manual adjustments in gloves was limited and could have contributed to an error. At times, physical evidence regarding the state or condition of the individuals involved in an event may also be collected, such as collecting urine or blood samples to test for the presence of drug metabolites. Assuring that perishable physical evidence is analyzed before it degrades, and that non-perishable evidence is controlled so that it is available for further analysis, if necessary, are two important challenges in gathering physical evidence.

Documentary evidence is also useful in understanding human performance problems, and particularly any programmatic causes for an error. Documents regarding the work activity in

which the human performance problem occurred help to establish what happened, who was involved and the conditions under which the problem arose. Examples of documentary evidence include:

- Event recordings (e.g., event history, computer printouts, automatic and manual plots of plant variables as a function of time showing the occurrence of alarms, system activations, and other conditions during the event). These documents may show, for example, the actions that were taken, when they were taken and any unusual conditions that existed at the time.
- Design drawings, specifications, design and installation procedures, modification packages. These documents may be useful in identifying discrepancies between how a system was designed and how it was functioning at the time an error occurred, for example. This information might allow the investigator to determine whether personnel were trained appropriately and whether the instructions and supporting information they had available during task performance were accurate.
- Maintenance records for affected systems, including vendor manuals. Maintenance records may be useful in determining, for example, the point in time at which an error during maintenance first occurred and, perhaps, how often it was repeated. Vendor manuals can be used to verify that procedures are up-to-date.
- Procedures and work orders used during or relevant to the event. These documents are very useful in establishing what happened in the event and in identifying discrepancies between what was planned versus what was implemented.
- Plant technical specifications and associated safety analyses. These documents are often useful in identifying discrepancies between what should have occurred versus what actually happened.
- Operations logs. Similar to event recordings, these documents may be helpful in establishing what happened and when.
- Correspondence, such as e-mails, letters, memoranda. These documents may also contain information that is useful in establishing the event timeline, but also often contain important information about the organizational work environment.
- Records of similar events, including root causes and corrective actions. These documents assist investigators in assessing the scope of the human performance problem as well as the effectiveness of previous corrective actions for similar human performance problems.
- Descriptions of programs, processes, and practices addressing plant operations and maintenance, personnel performance, and procedure development. These documents often clarify programmatic weaknesses, such as missing or weak barriers to error.

Human evidence is typically the primary source of information about human performance problems, and may include written statements, the results of interviews, recordings of human actions during the event or similar work activities, and the results of event reconstruction activities. For example, audio or videotapes of the situation that preceded or occurred during the event can be particularly useful for analyzing an error, but are usually not recorded. Tapes of similar work activities, such as those made of control room crews for training purposes, can be used to assess general work practices and may demonstrate an on-going human performance problem, or help to determine whether the particular error that occurred in an event is common.

Human evidence may also include demonstrations of critical actions, such as manipulations of the equipment involved in the event; walk through exercises, in which personnel act out important actions as the stages of a scenario are described or are directed by procedure steps; and dynamic exercises, in which scenarios are reenacted under more realistic conditions, such as in a training simulator. These evidence collection activities may provide information about possible task overload, for example, or deficiencies in the human-system interface, coordination and communication problems, knowledge or skill deficiencies, and so on.

The participants in an event are often available to the investigator and are typically able to provide the most detailed information about the error that occurred or the human performance problem. As discussed in Section 3, however, individuals' memories for events may be limited, if they are not interviewed immediately after the event. Further, they may not possess complete information about the event, because what they remember will be limited to the aspects of the event on which they were focused at the time. Or, memory for the event may be distorted from strong emotion, the passage of time and intervening thoughts, by hearing others' descriptions of what occurred or discussing it with them, the kinds of questions that are asked during the interview, and other factors. Licensee investigators should interview eyewitnesses who observed the event but did not participate in it as well as the event participants as soon as possible after the event.

The information obtained from different sources is often conflicting. Further evidence collection may resolve some conflicts. As a simple example, an operator may report in an interview that he entered a room at a particular time, but the entry records for that room show that he keyed in about 15 minutes later than he reported. Additional evidence regarding the accuracy and reliability of the clock used when recording entries may allow the investigator to conclude that the entry log is the more accurate information source. In other instances, it may not be possible to collect additional evidence to resolve conflicts. In these cases, investigators will have to weigh the evidence and use judgment to reach a conclusion. For example, if five eyewitnesses' descriptions of an event are consistent, but vary from the description given by the individual who committed the error, the investigator might conclude that the eyewitnesses' accounts were more valid.

It is often the case, however, that the evidence an investigator needs to conclusively establish what happened or why an error occurred does not exist or is unavailable. In these cases, investigators may have to assume that certain events occurred or conditions existed to explain the error, or may develop and analyze plausible alternative scenarios. Given that human performance is often so difficult to explain post hoc, it may be possible to derive some lessons learned from the investigation but not to develop corrective actions that will be effective in minimizing the likelihood that a similar error will reoccur.

As noted above, collecting evidence about a human performance problem is an iterative process. As answers to one question are found, other questions arise that require follow-up. In addition, new information may shed a different light on information collected earlier in the investigation or conflict with it, so that additional information collection is necessary.

In general, the evidence gathered about a human performance problem should enable licensee staff to identify several possible causes for the problem. Plausible causes should be documented and the licensee should gather further evidence to confirm or rule out the possibilities. The most plausible causes that were not confirmed by the evidence and the basis for rejecting them should also be documented.

4.4 TERMINATING THE INVESTIGATION

The licensee's basis for terminating the investigation of a human performance problem should also be documented. Theoretically, an investigation could continue until every question is fully resolved. Time and resources for conducting an investigation this thoroughly are usually not available, however. Therefore, other criteria may be applied to determine when an investigation should be terminated. These could include, for example, a pre-set deadline for completing the investigation, reaching a dead-end due to the unavailability of further evidence, or a decision that the problem under investigation is minor and does not warrant the expenditure of further resources. For events that the licensee has classified as significant, the investigation is typically not terminated until the investigator and licensee management concur that sufficient evidence has been gathered to support the determination of the causes of the human performance problem and to develop specific and effective corrective actions.

5 EVALUATING THE LICENSEE'S ROOT CAUSE ANALYSIS

5.1 INTRODUCTION

Root cause analysis is a systematic method for analyzing the evidence collected about a hardware failure or human performance problem. The purpose of root cause analysis is to identify the basic set of conditions that, if eliminated or modified, would minimize the likelihood of the same and similar problems from happening again. Performing a systematic root cause analysis and identifying the direct, contributing and root causes for human performance problems aids in ensuring that the problem is understood with sufficient depth to support the development of effective correction actions.

In this section, background information for evaluating licensees' root cause analyses of human performance problems is presented. The different types of causes that may be identified as a result of using root cause analysis techniques are discussed, and detailed information about three commonly used root cause analysis techniques is presented. These techniques are events and causal factors charting and analysis, change analysis and barrier analysis.

5.2 CAUSAL FACTORS

A **causal factor** is any action or condition that occurred or existed prior to an error without which the error is less likely have occurred. There are three types of causal factors that a root cause analysis will typically identify. These are the direct cause, contributing causes and root causes. Programmatic weaknesses are also often identified using root cause analysis techniques, and may be determined to be either contributing or root causes of a human performance problem. Apparent causes for an error may be identified by a licensee in problem reports for tracking and trending purposes, but are not derived from applying a formal root cause analysis technique.

A **direct cause** is the action or condition immediately preceding an error in an event sequence that caused or allowed the error to occur. For example, consider a situation in which an operator silenced what he thought was a nuisance high radiation alarm from an air monitor that had a history of spurious activations. Within a few minutes, however, it was discovered that the alarm was valid when several other air monitors in the same area also alarmed. The error here was failing to confirm whether the alarm was valid before silencing it. The investigation and analysis in this example showed that the direct cause of the error (i.e., the reason that the operator did not confirm the alarm's validity before silencing it) was the operator's belief that the alarm was invalid, based on its history of spurious activations. (Many other examples of typical direct causes for human errors can be found in Part II of this document, the HPEP Cause Modules.)

A **contributing cause** is the actions or conditions that set the stage for a human performance problem to occur, but, alone, were not sufficient to cause it. A contributing cause may be a long-standing condition or a series of prior events and problems that, while unimportant in themselves, increased the probability of error. For example, consider again the operator who silenced the high radiation alarm. In this case, the alarm's history of spurious activation would

be a contributing cause for the error, because it set the stage for the error, but, alone, did not cause it. Other operators at the site or at other plants might have assessed conditions in the area monitored before silencing the alarm, so the alarm's history contributed to the operator's action of silencing the alarm, but did not fully explain it.

A **root cause** of a human performance problem is the set of conditions that, if eliminated or modified, would minimize the likelihood that the problem would reoccur as well as prevent similar problems from occurring. A root cause is often responsible for multiple human errors or hardware failures, rather than single problems. Root causes are more fundamental causes than direct causes, affect a wider scope of work activities, are both necessary and sufficient to cause the problem, and are often the results of programmatic weaknesses. In the case of the alarm error, a deficiency in alarm response procedures, supervision or training may have allowed a practice to develop of silencing alarms without verifying conditions. If so, weaknesses in the procedures or training programs could be a root cause of the error and some other operators at the plant, who use the same procedures or have received the same training, may be likely to commit the same error. Weaknesses in immediate supervision, such as the failure to communicate and enforce management expectations regarding alarm verification before silencing, could also be a root cause of the error.

A **programmatic cause** is a deficiency in one of the licensee's programs for managing work activities at a site that allows human errors to occur and may be the root cause of a single error as well as an adverse human performance trend. Licensee programs, such as the procedures and training programs, overtime policies and practices, or the fitness-for-duty program, are implemented by management to create and maintain barriers to errors. When weaknesses exist in these programs, or their implementation is flawed, the barriers to error they are intended to maintain may be ineffective. In the alarm example discussed above, a failure to emphasize alarm verification, even of nuisance alarms, in the operator training program would be a programmatic cause of the operators error, as well as a possible root cause. Other examples of common programmatic causes for human performance problems can be found in Part II of this document, the HPEP Cause Modules.

Many licensees also identify apparent causes for human performance problems that are perceived as having little individual significance but that will be tracked to enable monitoring of developing trends. An **apparent cause** is typically an estimate of the direct cause of an event or problem, based upon a limited investigation. An apparent cause is identified without using standard root cause analysis techniques.

Using standard root cause analysis techniques is not a regulatory requirement. The licensee is required under 10 CFR 50 Appendix B Criteria XVI to prevent the recurrence of "significant conditions adverse to quality," however, and many licensees have concluded that the use of standard root cause analysis techniques is beneficial in understanding and correcting these significant conditions. Licensees specify the criteria for determining significance, which may include issues of risk, regulatory requirements and economic considerations. Other conditions that are "adverse to quality," but do not meet the licensee's significance criteria, may be assigned an apparent cause on the basis of a cursory investigation and without a formal root

cause analysis. In some cases, the licensee may elect to track these low-risk conditions and monitor adverse trends for a larger number of similar conditions. If the trending indicates a common or related cause for these conditions, then a root cause determination may be required by the licensee's policy or administrative procedures.

5.3 OVERVIEW OF ROOT CAUSE ANALYSIS TECHNIQUES

Root cause analysis relies to some extent on judgment. However, structured root cause analysis techniques provide step-by-step procedures that can be repeated and verified. Clear documentation of the analysis allows a reviewer to check its accuracy and completeness.

Several root cause analysis methods that may be used in licensee facilities are listed below:

- Events and causal factors analysis (to identify the events and conditions that led up to the human performance issue)
- Change analysis (to identify changes in the work environment since the job was last performed successfully that may have caused or contributed to the problem)
- Barrier analysis (to identify the barriers that, if present or strengthened, would have prevented the human performance issue from occurring)
- Management Oversight and Risk Tree (MORT) analysis (to systematically check that all possible causes of problems have been considered)
- Critical incident techniques (to identify critical actions that, if performed correctly, would have prevented the event from occurring or would have significantly reduced its consequences)
- Fault tree analysis (to identify relationships among events and the probability of event occurrence)

In general, a root cause analysis repeatedly asks the question "Why?" about the events and conditions that caused or contributed to the human performance problem.

Once the evidence has been gathered and the important causes for the human performance problem have been identified, the root cause analysis then looks for any relationships among the causes. The root cause analysis determines whether the causal factors demonstrate any order or precedence, either in terms of time or scope of effect. If one causal factor preceded another in time and affected it, or if a causal factor accounted for more than one of the human errors that occurred in an event sequence or among those comprising an adverse human performance trend, it is a candidate root cause. The goal of the analysis is to determine which causal factor(s), if corrected, would prevent the recurrence of the same and similar errors. Events and causal factors charting and analysis, change analysis and barrier analysis work well together to ensure that all causal factors are identified.

5.4 EVENTS AND CAUSAL FACTORS CHARTING AND ANALYSIS

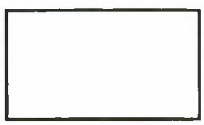
Events and causal factors charting and analysis is a method for organizing and analyzing the evidence gathered during an investigation. An events and causal factors (ECF) chart graphically

displays the events and conditions associated with an occurrence (e.g., an error, a significant event, a human performance problem) the user wishes to understand. In an ECF analysis, the chart is used to identify the causal factors associated with the hardware failure or human performance problem.

5.4.1 Events and Causal Factors Charting

An ECF chart is comprised of symbols that represent the important events and conditions that led up to the hardware failure or human performance problem under investigation. An **event** in an ECF chart is any action or occurrence that happened at a specific point in time relative to the hardware failure or human performance problem under investigation. A **condition** is a state or circumstance that affected the sequence of events in the ECF chart.

Some of the symbols that may be used for ECF charting are as follows[2]:

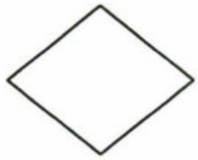


A rectangle is typically used to indicate an event. A brief description of the event is written within the symbol as well as the date and time at which the event occurred. Events are arranged in a line in chronological order from left to right.

Events that are assumed to have occurred, but for which no validated evidence exists or has yet been collected, may be indicated by a rectangle outlined with dashed lines.

An oval is typically used to indicate a condition. A brief description of the condition is written within the oval and the condition is placed above the event it affected on the chart.

A condition that is assumed to have existed, but for which no validated evidence exists or has yet been collected, is indicated by an oval outlined with dashed lines.

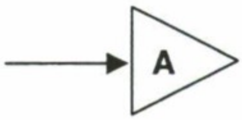


A diamond is used to indicate the occurrence of interest, such as a significant event.

[2] The symbols used for charting are unimportant. Any symbol set or other method to differentiate among events, conditions, causes and their inter-relationship, such as color-coding, may be used in the chart.

Arrows are used to connect events, and to connect conditions to events.

An octagon may be used to indicate a causal factor and is placed above the events or conditions it caused.



Triangles are used to connect event lines that must be broken when, for example, the entire sequence of events will not fit on a page.

An example of an ECF chart can be found in Figure 5-1. This example depicts a partially completed ECF chart for an operational event in which the residual heat removal (RHR) system was overpressurized during initial pressurization of the reactor coolant system (RCS) following a refueling outage (NUREG/CR-5953, 1992).

Events and causal factors charting was developed to support the investigation of a single event. It can also be used to identify human performance problems. Developing ECF charts for the different errors that may represent an adverse trend and comparing them allows the detection of patterns and similarities in the events and conditions associated with the different errors.

5.4.2 Events and Causal Factors Analysis

Analysis of the ECF chart begins after the investigation is completed, although the analysis itself may raise additional questions that require further investigation. The analysis is performed to identify direct, contributing and root causes for the hardware failure or human performance problem of interest. The analysis consists of first identifying the significant events in the timeline and then evaluating them by asking a number of questions about each one.

An ECF chart will often contain events that did not play a causal role in the human performance problem under investigation, but must be included to "tell the story," so that others can understand what happened. These other events may be retained in the chart, but only the significant events will be analyzed.

Identifying the **significant events in the ECF chart** starts with the event that came immediately before the hardware failure or human performance problem of interest. To determine whether this event is significant or not, the question is asked, "If this event had not occurred, would the

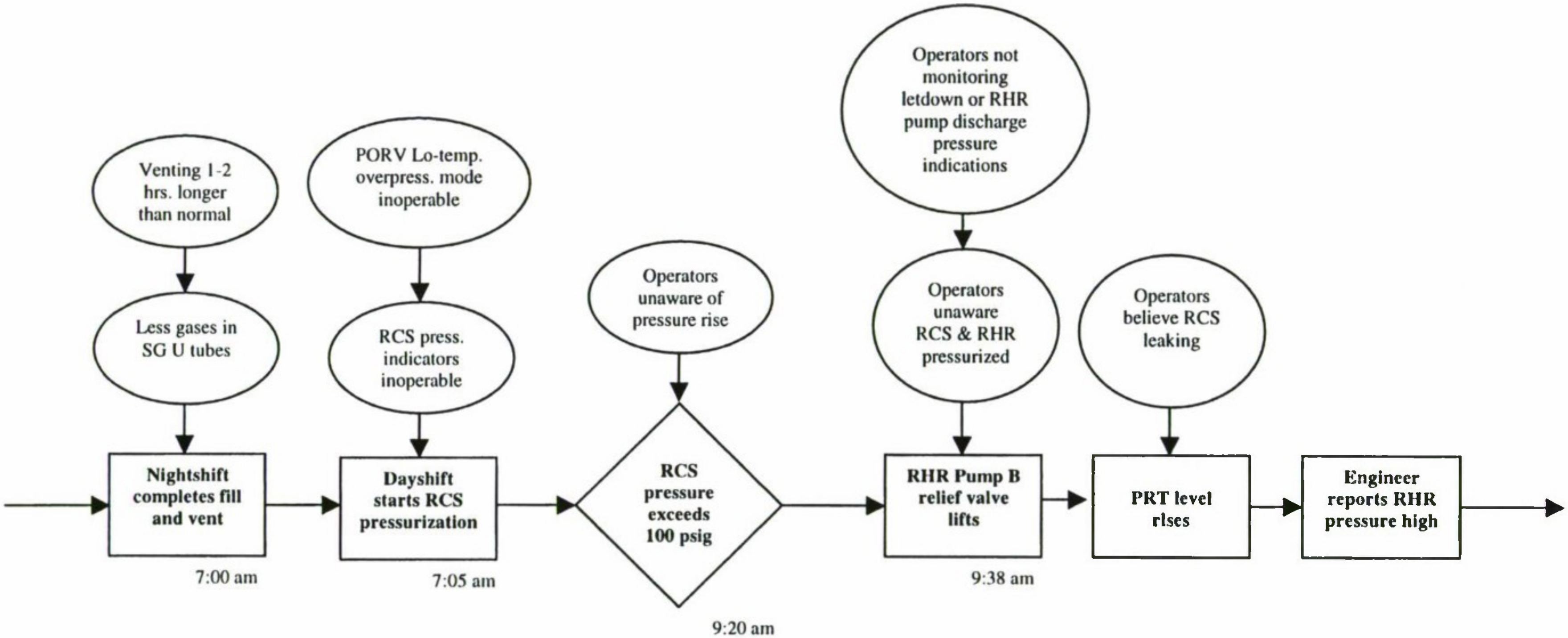


Figure 5-1. Partial ECF Chart from March, 1990 RHR Overpressurization Event

failure have occurred?" If the answer to this question is, "Yes," then the question is asked whether the event represented a normal activity with the expected outcomes. If it was a normal activity with the expected outcomes (e.g., the maintenance technician arrived at work, control rods were inserted and the reactor scrammed), then it is not a significant event in the chart. If the event had unplanned or unwanted consequences, then it is a significant event in the chart and should be further analyzed by asking the following additional questions:

- What were the other events and conditions that led to the significant event?
- What went wrong that allowed the event to occur?
- Why did those conditions exist?
- Were other significant events necessary for the failure or problem to occur or would the recurrent of this event alone lead to another failure or problem?
- Is the significant event linked to other events or conditions that may indicate a more general or larger deficiency, such as a programmatic weakness?

For example, in Figure 5-1, the event in the chart that precedes the overpressurization was the control room crew initiating system pressurization. Starting RCS pressurization is a significant event in this timeline, because, obviously, RCS could not have overpressurized without it and because initiating pressurization had unplanned and unwanted consequences.

The significant events in an ECF chart, and the events and conditions that were responsible for them, are causal factors. A brief statement that summarizes the relevant characteristics of the causal factor is added to the ECF chart above the significant event to which it applies. Figure 5-2 shows the ECF chart for the overpressurization event with one causal factor added above the conditions and event in the chart to which it applies.

When each significant event in the chart has been analyzed, relationships among the causal factors may be revealed. For example, in some situations, several examples of training weaknesses may be identified or the failure of one piece of equipment or system is found to have caused several of the events in the chart. When common causes are found, they may indicate the root cause of the problem under investigation.

5.5 CHANGE ANALYSIS

Changes in the work environment often result in unanticipated and unwanted consequences. **Change analysis** involves systematically identifying and analyzing any changes that may have affected the problem under investigation.

Many types of changes may lead to unwanted consequences. These could include, for example, changes in

- the characteristics or number of workers involved in the task
- other work activities going on concurrently with the work activity of interest
- equipment condition or status
- the work location or the environmental conditions in which the work was performed

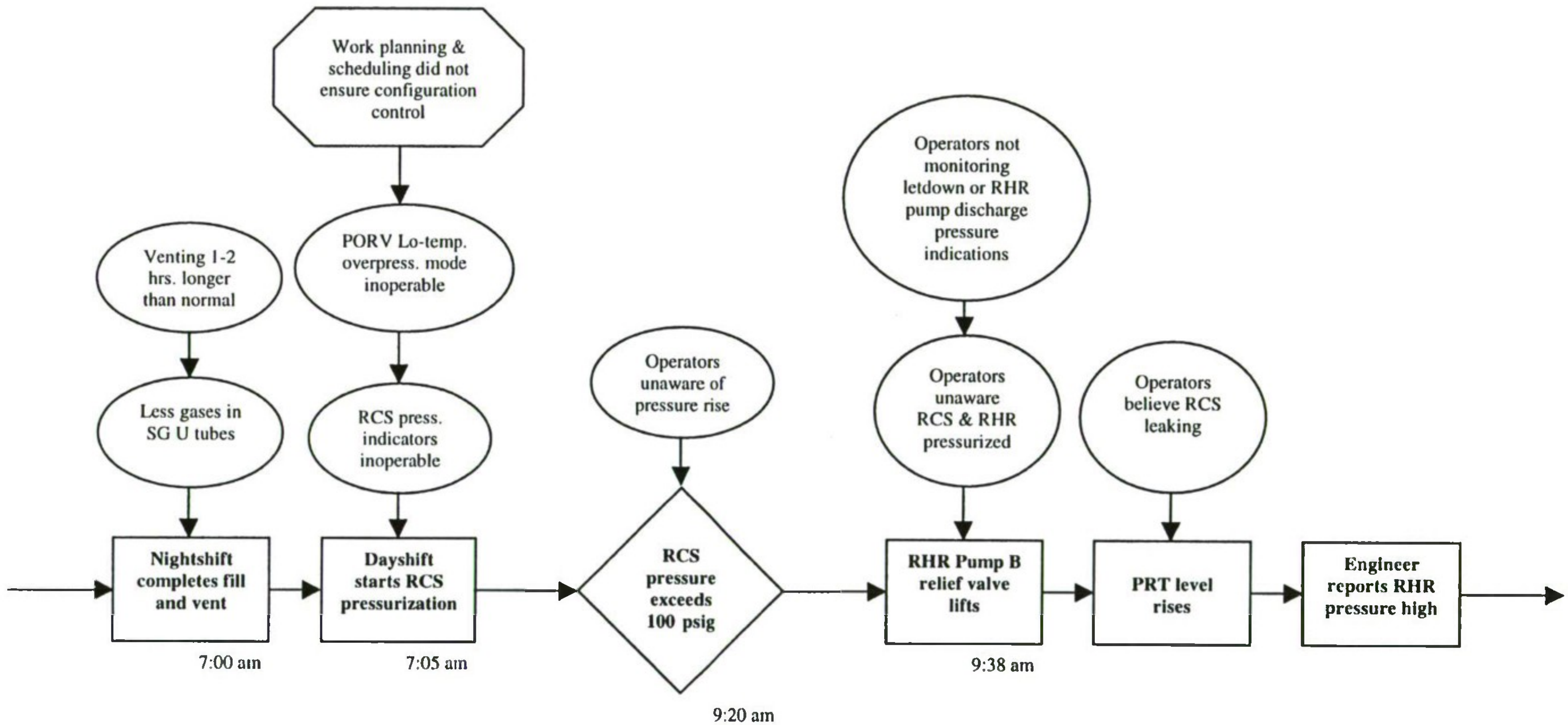


Figure 5-2. Partial ECF Chart from March, 1990 RHR Overpressurization Event with One Causal Factor Added

- supervision
- management expectations for the work.

Changes that may lead to an unwanted occurrence can be difficult to detect in advance because change is pervasive. Change control processes, such as reviewing the safety implications of planned changes, are one method to ensure that changes do not have a negative impact on safe operations. Formal reviews or risk analyses sometimes miss important conditions, however. There also are many avenues for introducing changes to the work environment that do not appear to be sufficiently risky to warrant formal review.

Change analysis for human performance problems is most effective when the same work activity has been performed successfully in the past, when the work activity and conditions under which it was performed were documented or can be reconstructed, and when procedures for performing the work are available. Change analysis can also be performed by comparing the work activity under investigation to how the work activity is successfully performed at other sites, or to "ideal" situations as documented in standards and regulations.

The first step of a change analysis is to define the "event-free situation" and compare it to the situation in which the "event" under investigation occurred. The "event" may be any hardware failure, human error or human performance problem. The "event-free" situation is a comparable situation in which the hardware did not fail or the work activity was performed successfully.

Once the "event" and "event-free" situations have been identified, they are analyzed to determine the specific differences between them. The impact of each difference on the event is then evaluated to determine whether the change was unimportant or was a direct, contributing, root and/or programmatic cause of the problem.

Table 5.1 shows an example of a change analysis worksheet for the overpressurization event discussed previously. The human error of interest is the operators' failure to detect and control the rapid rise in RCS pressure. As can be seen in Table 5.1, four changes from previous occasions on which RCS pressurization activities were performed successfully were identified.

Evaluating the causal roles of these changes involves asking, for each change, whether or not it meets the definition of a direct, contributing, root and/or programmatic cause, or did not play a causal role in the error. In this example, the inoperability of the RCS pressure transmitters was the direct cause of the error, because it was "the action or condition immediately preceding the error in the event sequence that caused or allowed the error to occur." If the RCS pressure transmitters were operable, the crew would have detected the rapid pressure increase in time to control it and prevent the transient. Evaluation of the roles of the other four changes, based on the evidence available, indicates that they were contributing causes. That is, each of the changes, alone, did not cause the error, but rather set the stage for it. It was the combination of these additional changes with the inoperability of the RCS pressure indications that allowed the event to occur.

Table 5.1 Example Change Analysis Worksheet for an RCS Overpressurization Event

Event Situation	Event-Free Situation	Difference	Effect on Event
RCS pressure instrument transmitters isolated for maintenance	RCS pressure indicators operable	No accurate indications of RCS pressure were available	Operators were unable to monitor RCS pressure
Fill and venting of reactor head extended	Fill and vent evolution completed within normal time limits	Venting continued 1-2 hours longer than normally	The longer vent and fill evolution decreased the volume of gases in the steam generator (SG) U tubes
Reduced volume of gases in SG U tubes caused by longer vent time	Greater volume of gases in SG U tubes	Reduced amount of non-condensable gases caused RCS pressure to increase sooner than in previous refill operations	RCS pressure rose sooner then expected and approached 100 psig within 2.5 hours of initiating pressurization
Operators were monitoring the inoperable RCS pressure gauges, but not all available pressure indications (e.g., letdown and RHR discharge pump pressure gauges)	Operators monitored all available pressure indications	Operators did not detect indications of the rapid pressure increases on the letdown and RHR discharge pump pressure gauges	An opportunity to detect the pressure rise and prevent the overpressurization was missed

5.6 BARRIER ANALYSIS

The **barrier analysis** technique can also be used to identify causes for human performance problems. The purpose of a barrier analysis is to identify the barriers to error that were missing, bypassed or failed and their causal roles. Barrier analysis also shows the barriers that succeeded and prevented the problem from having more serious consequences.

Barrier analysis is based on the concept that **hazards** represent potentially harmful energy flows or environmental conditions from which **targets** (i.e., personnel and equipment) must be protected. Hazards to personnel may include, for example, radiation, electrical energy, chemical and biological agents or adverse environmental conditions. Hazards to equipment may include human error, damage from wear and tear or natural phenomena.

A **barrier** is any means used to protect targets from hazards. There are two basic types: physical and management barriers. Examples of typical physical barriers used in industrial settings to protect personnel are fences, guardrails around moving equipment, protective clothing and safety devices. Management barriers used to protect equipment in nuclear licensee facilities

include preventative and corrective maintenance as well as supervision, training, the design of the human-system interface or procedures to reduce the likelihood of damage from human error. The barriers that could or should have been in-place and how they should have functioned can be identified from subject matter expertise, knowledge of industry good practices, licensee policies and procedures, design basis documents and regulations.

A barrier analysis is performed in five steps. The first step is to identify the hazard and target. The second step is to identify all of the barriers that could have protected the target from the hazard. The third step is to evaluate how each barrier performed. That is, did the barrier succeed or fail? For barriers that failed, the fourth step is to determine why they failed. Finally, the causal role of each barrier is evaluated to determine whether it was a direct, contributing, root and/or programmatic cause.

This technique is particularly useful in providing the basis for developing corrective actions to prevent the same or a similar problem from happening again. Corrective actions can strengthen existing barriers that failed or erect barriers where they are missing.

Table 5.2 shows an example of a barrier analysis worksheet for the RCS overpressurization event. In this example, the hazard would be pressure and the target would be the catastrophic failure of the reactor coolant or residual heat removal system piping.

Evaluating the causal role of each failed barrier involves asking whether or not it meets the definition of a direct, contributing or root cause, or did not play a causal role in the error. In this example, the inoperability of the RCS pressure transmitters again meets the criterion for the direct cause of the error, because it was "the action or condition immediately preceding the error in the event sequence that caused or allowed the error to occur." Further, if the RCS pressure transmitters were operable, two additional physical barriers would not have failed: the power-operated relief valves (PORVs) low-temperature overpressure protection and the computer alarm. Because the failure of these barriers was dependent upon the RCS pressure transmitters being inoperable, they are contributing causes of this event.

As can be seen from this example, barrier analysis is an effective method to begin identifying programmatic causes as well as potential corrective actions. For example, had the RCS pressure indicators been tagged out-of-service, it is unlikely that the operators would have started RCS pressurization activities until these indications were available. The station's policy of excluding control room instrumentation from the tagout program indicates that the scope of the tagout program may have been a programmatic weakness that, if corrected, could have prevented this event and other, similar events. However, responsibility for configuration control lies with the work management program. Had the work planners (or an independent review) recognized that the RCS indicators were not available for initial RCS pressurization and ensured that they were, the rate of the pressure rise and the operators' focus on the three RCS indicators would not have mattered because accurate pressure indications would have been available to detect and control pressure. Therefore, the startup procedure and the operators' status monitoring were contributing causes to the event, but not root causes. Further investigation of the work management program

Table 5.2 Example Barrier Analysis Worksheet for Overpressurization Event

Hazard: Pressure		**Target:** Catastrophic failure of system piping	
Physical Barriers	**Performance**	**Why Did it Fail?**	**Effect on Event**
RCS pressure instrument transmitters	Failed	Out of service for maintenance	RCS pressure indicators inoperable so operators could not detect rapid pressure rise
Power-operated relief valves (PORVs) low-temperature overpressure protection	Failed	The two wide-range RCS pressure instruments were the sensors for the PORV low-temperature over-pressure protection mode	PORV low-temperature over-pressure protection unavailable
RHR Pump B suction relief valve	Succeeded in stopping uncontrolled pressure rise		Maintained pressure below limits – prevented catastrophic failure of RHR piping
Pressurizer relief tank (PRT) level indication	PRT level increased when RHR suction relief valve opened		Succeeded in alerting operators to problem situation
Annunciators	Missing	RHR pressure did not reach alarm actuation setpoint and computer alarm came off the inoperable pressure transmitters	No audible indications of pressure rise
Management Barriers	**Performance**	**Why Did it Fail?**	**Effect on Event**
Startup procedures	Did not control RCS vent evolution	Fill and vent procedure did not specify a time limit for venting gases from reactor head	Night shift extended the RCS vent evolution 1-2 hours longer than normal, reducing the volume of gases remaining in the SG U tubes
Work management (planning and scheduling)	Failed	Work planners overlooked the need for the RCS pressure instruments to be operable before initial pressurization of the RCS	Pressurization was initiated without RCS pressure indications operable
Independent review	Missing	Not performed or required	Failed to identify the RCS pressure instrument isolation
Tagging out-of-service control room instruments	Missing	Tagging of out-of-service instruments in control room not required by tagout program	There was no visual cue that the three RCS pressure indicators were inoperable
Systems monitoring	Inadequate	Operators were focused on the RCS pressure indicators and were not monitoring all pressure indications available	Operators did not notice other indications of the pressure rise that indicated RHR, CVCS and RCS were pressurized

would be necessary to identify the specific weaknesses that allowed this event to occur, as well as the corrective actions necessary to strengthen the program. However, flaws in the work management program appear to have been the root cause of the operators' error in this event.

5.7 COMBINING TECHNIQUES

Practical experience has shown that different root cause analysis techniques provide different perspectives on an event. As a result, using a combination of methods ensures that a more complete set of causal factors is identified.

Because different root cause analysis techniques ask different questions about a human performance or hardware problem, the causes that are identified may differ. Compare, for example, the differences in the causal factors above that resulted from the change and barrier analyses for the overpressurization event. For the overpressurization event, the barrier analysis yielded a larger number of causal factors and led to the identification of the root causes of the event. For other events, changes may be the key causal factors and barrier analysis used alone may not identify them.

No matter which root cause analysis techniques are used by a licensee, the purpose of the analysis is to identify the causal factors that, if corrected, would minimize the likelihood that the same and similar "significant conditions adverse to quality" will occur again. The effectiveness of a problem identification and resolution program rests less on the root cause analysis techniques used than on the thoroughness of the investigation conducted, assurance that the key causal factors have been identified, and the development and implementation of the corrective actions suggested by the analysis.

6 EVALUATING CORRECTIVE ACTION PLANS

6.1 INTRODUCTION

An effective **corrective action** for a human performance problem is one that will minimize the likelihood of the problem happening again. Developing effective corrective actions for human performance problems requires a thorough root cause analysis and an understanding of methods for enhancing human performance.

In this section, background information for evaluating corrective actions plans is presented. The different types of corrective action plans and issues in implementing them are discussed.

6.2 CORRECTIVE ACTION PLAN SCOPE

Corrective action plans, which incorporate corrective actions for human performance problems, vary in scope. The scope of the plan is determined by the significance of the error or adverse trend as well as the extent of the conditions created by the causal factors identified. Three types are described below.

The broadest type is a **general organizational improvement plan**. This type of plan usually involves all or a large number of the work groups at a site and, sometimes, corporate headquarters. Its purpose is to make significant changes in how work is done and how it is managed in order to improve operational performance and to reverse declining performance trends. Corrective actions may address problems in any aspect of plant operations, such as

- changing the organizational structure
- changing managers' spans of control
- improving manager capabilities and competence
- improving worker training and qualification programs
- revising the hierarchical family of vision, goals, objectives, policies, programs, processes, procedures and practices.

General organizational improvement plans are typically required to correct a safety culture problem in an organization.

An **intermediate scope corrective action plan** focuses on adding to or strengthening the programs that are responsible for maintaining barriers to human performance problems. Typical programs that are implemented to maintain barriers to error are:

- programs for developing procedures, keeping them updated and requiring their use for certain jobs
- human resources programs for selecting and promoting personnel
- behavioral safety programs such as STAR (Stop, Think, Act, Review)

- human-system interface design programs, such as the program responsible for ensuring that labels on parts and equipment are accurate and legible
- management systems for defining and organizing work flow
- quality control programs.

Limited scope corrective action plans focus on fixing the direct cause of an error. These plans add or strengthen specific barriers.

Corrective actions to add new barriers might include:

- writing a procedure for a task that previously depended on "skill of the craft"
- moving personnel with operations experience into the work planning group
- developing a new training module for maintenance workers, or
- replacing an analog display with a new digital display that is more accurate and easier to read.

Corrective actions to strengthen existing barriers could be redesigning an existing training module or adding a requirement for a supervisor to be present when a particular job is performed. Most limited corrective action plans use a combination of adding new and strengthening existing barriers.

Sometimes correcting the direct cause of an error will prevent that specific error from recurring but fail to prevent similar errors. For example, if the direct cause of an error was an ambiguous procedure step, fixing that one step may stop others from making the same error when performing that step. But fixing that step in the procedure will not correct other ambiguous steps in the same procedure or in other procedures. If the ambiguous steps have the same root cause, such as a procedure writer in need of additional training, the root cause must be corrected to prevent future errors due to poorly written procedure steps.

Corrective action plans must also address any adverse conditions that were created by a human performance problem, based upon the assessment done of the extent of the conditions created by a causal factor. For example, if an instrument is miscalibrated and the cause is determined to be an error in a miscalibration procedure, the corrective action plan must include actions not only to ensure that the instrument is re-calibrated correctly, but also that other instruments governed by the same procedure are also calibrated correctly.

The appropriate scope of a corrective action plan depends upon the nature of the causal factors identified in the root cause analysis, their scope and the risks they pose. Licensees may use probabilistic risk assessment or human reliability analysis methods to choose among corrective action alternatives.

6.3 ACCOUNTABILITY FOR HUMAN PERFORMANCE

Some corrective actions in a corrective action plan may focus on the individual worker who committed an error. These corrective actions may include, for example, remedial training, participation in the investigation and root cause analysis, loss of qualification for a period of time and/or time off work.

Corrective actions that focus on the individual worker are often ineffective. Routinely placing responsibility for errors on the individual workers adversely impacts a licensee's safety culture and may discourage personnel from reporting errors or raising concerns. A "blame the worker" approach to human performance may result in adversarial relations between workers and supervisors, which will hinder effective communication and teamwork. On the other hand, it may be appropriate to hold workers accountable for errors if they have been provided with the necessary resources to perform their tasks correctly. These resources include relevant training, usable and technically accurate procedures, well-designed tools and equipment, accurate drawings, labels on equipment and other operator aids, and clearly defined and specific management expectations for performing each task. Industry experience has shown that improving human performance requires balancing the organization's responsibility for providing personnel with the tools and resources they need to accomplish their tasks with individual accountability for performance to reasonable standards.

6.4 CORRECTIVE ACTION PLAN COMPLETENESS

An important requirement for corrective action plan effectiveness is completeness. A complete corrective action plan addresses each of the causal factors that were identified from the root cause analysis. In some cases, a single corrective action may address more than one causal factor. For example, if a root cause analysis has identified several weaknesses in work planning and scheduling, the licensee may decide to re-engineer the entire work management program. Often, several corrective actions may be developed to address one causal factor. More than one corrective action may be required because the causal factor is complex or the licensee wishes to ensure there is "defense-in-depth" against a recurrence of the human performance problem.

6.5 PLAN IMPLEMENTATION AND EFFECTIVENESS

Corrective action plans that appear to have an appropriate scope and to be complete may be ineffective when they are implemented. Corrective action plan implementation may be ineffective for several reasons.

A common reason that corrective action plans fail is that detailed information from the problem investigation and root cause analysis is not communicated to those who are assigned responsibility for developing and implementing the corrective actions. The detailed information about the human performance problem that has been collected is usually not recorded in the investigation report or presented in a briefing. Further, information collected about human performance problem may include sensitive personnel matters that are not documented. A

detailed understanding of the human performance problem is necessary for corrective action effectiveness, however, because these problems are typically complex with multiple, interacting causes. Ensuring that the individuals involved in investigating and analyzing human performance problems work closely with the personnel responsible for the corrective action plans improves the likelihood that the plans will be effective.

Other commonly identified reasons for ineffective corrective action plans are:

- **Responsibility not assigned**. Responsibility for developing, implementing and monitoring the effectiveness of corrective actions may not be assigned to specific individuals who are held accountable for them. Responsibility for corrective actions may be assigned to a department or to "management," rather than to individuals who have the expertise, authority and resources to ensure they are implemented.

- **Staffing changes.** Personnel change jobs and the individuals who developed and began implementing a corrective action plan may move on to other positions. The information they had about the basis for a corrective action plan may not be communicated to their successors.

- The steps for achieving the plan's **objectives are not defined**. Some corrective action plans define the goals to be achieved, but not the steps required to achieve them. Corrective action implementation is typically most effective when project management techniques are used, such as defining milestones and deliverables, a project schedule, the resources required, and so on.

- **Competition for resources**. Other management initiatives and events arise that take precedence over implementing the corrective actions.

- **Measurement.** Corrective action plans may fail because measures for determining the success of the corrective actions were not defined and used to refine the plan when necessary.

- **Unintended consequences.** Corrective actions may have unforeseen, unintended consequences that cause them to fail.

For human performance problems that have a relatively high risk significance, the licensee may schedule effectiveness reviews for the corrective action plan that was implemented. **Corrective action effectiveness reviews** are analyses of whether the corrective actions in a plan have worked as intended. They are typically scheduled weeks or months after a corrective action has been implemented and has had time to demonstrate an effect. The schedule for conducting effectiveness reviews and the measures of effectiveness that will be used may be included in the initial corrective action plan.

6.6 CONCLUSION

The most important test of a corrective action plan is whether it succeeds in minimizing recurrence of the human performance problem it is designed to address. As discussed in Section 3, however, the recurrence of a problem behavior does not necessarily indicate that a corrective action plan is ineffective because the same behavior can result from many different causal factors. The corrective action plan may have been effective in controlling one cause for a particular behavior, but other causes may still exist. These other causes could not have been identified in the investigation and analysis because they did not play a role in the original problem. Investigation and causal analysis of the recurrent problem behavior would be necessary to determine whether the corrective action plan for the initial problem was ineffective or whether the recurrent problem is due to other causes that would then need to be addressed.

THE HUMAN PERFORMANCE EVALUATION PROCESS

Part II: The HPEP Cause Tree and Modules

7 OVERVIEW OF THE HPEP CAUSE TREE AND MODULES

7.1 INTRODUCTION

Part II of the Human Performance Evaluation Process (HPEP) is comprised of the HPEP Cause Tree and Modules. The HPEP Cause Tree is a screening tool for identifying the range of possible causes for a human performance problem. The Cause Modules discuss typical causes of human performance problems in nuclear licensee facilities and provide examples of frequently identified direct and programmatic causes, based upon the research literature and industry experience.

The Cause Tree and Modules are not a complete list of all possible causes for human errors. In practice, the evidence that is collected in an investigation and the results of causal analyses are necessary to determine an error's actual cause(s). The primary value of a list of possible causes, such as those presented here, is that it prompts consideration of a range of causes. Used as a checklist, the Cause Tree and Modules assist in overcoming the tendency to arrive at conclusions too early in an investigation or to only investigate the possibilities that are initially suggested when an error is committed. Thus, the Cause Tree and Modules are intended to be used heuristically, but the possible causes that are investigated must be derived from the evidence.

7.2 USING THE CAUSE TREE AND MODULES

Part II is for use by inspectors to verify the causes that a licensee has identified for human performance problems in order to complete Table 2.3, Causal Analyses, in Part I. The HPEP Cause Tree and Cause Modules may also be used as guidance in conducting an event investigation and to identify a human performance trend.

7.2.1 Verification

The HPEP Cause Tree and Modules are intended to assist in evaluating a licensee's causal analyses of human performance problems. In general, a causal analysis that is complete and valid will also be reliable. That is, it will yield similar results when repeated by another individual or team, although the specific terminology used to describe the cause(s) will likely differ. By answering the questions in the Cause Tree and reviewing the information in the appropriate Cause Modules, the inspector could verify that the evidence the licensee has gathered supports the causes identified and that other plausible causes can be ruled out.

To verify the licensee's conclusions, the inspector may (1) use the information available in the licensee's documentation of the investigation or collect evidence independently, (2) answer the questions in the Cause Tree and then (3) review the information in the appropriate Cause Modules to determine whether or not the licensee correctly identified the causes of a human performance problem. If the inspector arrives at direct and programmatic causes that are similar to those documented by the licensee, based upon the same evidence, it is likely that the licensee has accurately identified the causes for the human performance problem. If the inspector arrives at different direct and programmatic causes, then the Cause Modules may be used to identify additional information to request from the licensee. Or, the inspector may use the Cause

Modules to determine the lines of inquiry for an independent investigation. In most cases, discrepancies between the inspectors' cause(s) and the licensee's will be resolved on the basis of the evidence.

7.2.2 Conducting an Independent Event Investigation

If an inspector or NRC inspection team is conducting an independent event investigation, the Cause Tree and Modules can be used to understand the human errors that occurred in the event. The Cause Tree and Modules may be used to identify promising lines of inquiry to explore in the investigation. They may also serve as a checklist to ensure that possible causes for the error(s) have not been overlooked.

The Cause Tree will streamline an investigation by directing inspectors to the most likely causes of an error. Further evidence can then be collected regarding a specific cause to support the causal analysis. The lists of possible direct and programmatic causes within the Modules may be used to develop the specific lines of inquiry. For example, the Cause Tree would prompt inspectors to ask, "Were there weaknesses in the procedures used to perform the task?" If the answer were "yes," then the Procedures Module in Section 11 would prompt the investigators to further ask, "What were the procedural weaknesses and did they cause or contribute to the error? Were there systematic weaknesses in the procedures or another program that allowed these flaws in the procedure to exist? Are other licensee procedures similarly affected?"

As the investigation matures, the Cause Tree and Modules can be reviewed again to verify that potential causes have not been overlooked. Often the evidence that is gathered indicates that different causes than originally identified should be investigated. Repeated reference to the Cause Tree and Modules during the course of an investigation may help to assure that the investigation is complete and that sufficient evidence has been gathered to support the team's conclusions.

7.2.3 Identifying a Human Performance Trend

The Cause Tree and Modules may also be helpful in identifying a human performance trend. A human performance trend may be indicated if one cause category, such a procedures or supervision, is repeatedly identified by the licensee in a sample of problem reports, or appears to the inspector to be implicated in numerous problem reports.

To verify that a human performance trend has developed, however, it is important that the human errors are investigated and analyzed sufficiently to identify the direct and programmatic causes with some confidence. By definition, a human performance trend is a pattern of related errors resulting from the same causal factor. Therefore, licensee reports of the apparent causes of an error may be suggestive, but even a large number of reports citing a particular cause category do not establish the existence of a human performance trend unless the direct and programmatic causes of the errors are known.

7.3 ORGANIZATION

The HPEP Cause Tree is presented in Figure 7-1. The HPEP Cause Modules are presented in Sections 8 through 18. The Cause Tree asks a series of questions about the conditions surrounding a human error of interest. Based upon the answers to those questions, the inspector is referred to the appropriate Cause Modules. Each Cause Module is comprised of causal factors that have been found to affect human performance in the workplace as follows:

Personnel – These Cause Modules discuss characteristics that individual workers bring to the job that may affect task performance, such as

Section 8:	Fitness for Duty
Section 9:	Knowledge, Skills and Abilities
Section 10:	Attention and Motivation

Resources – These Cause Modules discuss characteristics of the resources available to personnel to assist in performing their tasks, such as

Section 11:	Procedures and Reference Documentation
Section 12:	Tools and Equipment
Section 13:	Staffing
Section 14:	Supervision

Work Environment – These Cause Modules discuss characteristics of the work environments in which personnel perform tasks, such as

Section 15:	Human-System Interface
Section 16:	Task Environment

Communication and Coordination – These Cause Modules discuss characteristics of the human interactions required to perform a task correctly, such as

Section 17:	Communication
Section 18:	Coordination and Control

Within each Cause Module, background information is presented regarding the effects of each causal factor on human performance and examples of typical direct and programmatic causes for errors are listed.

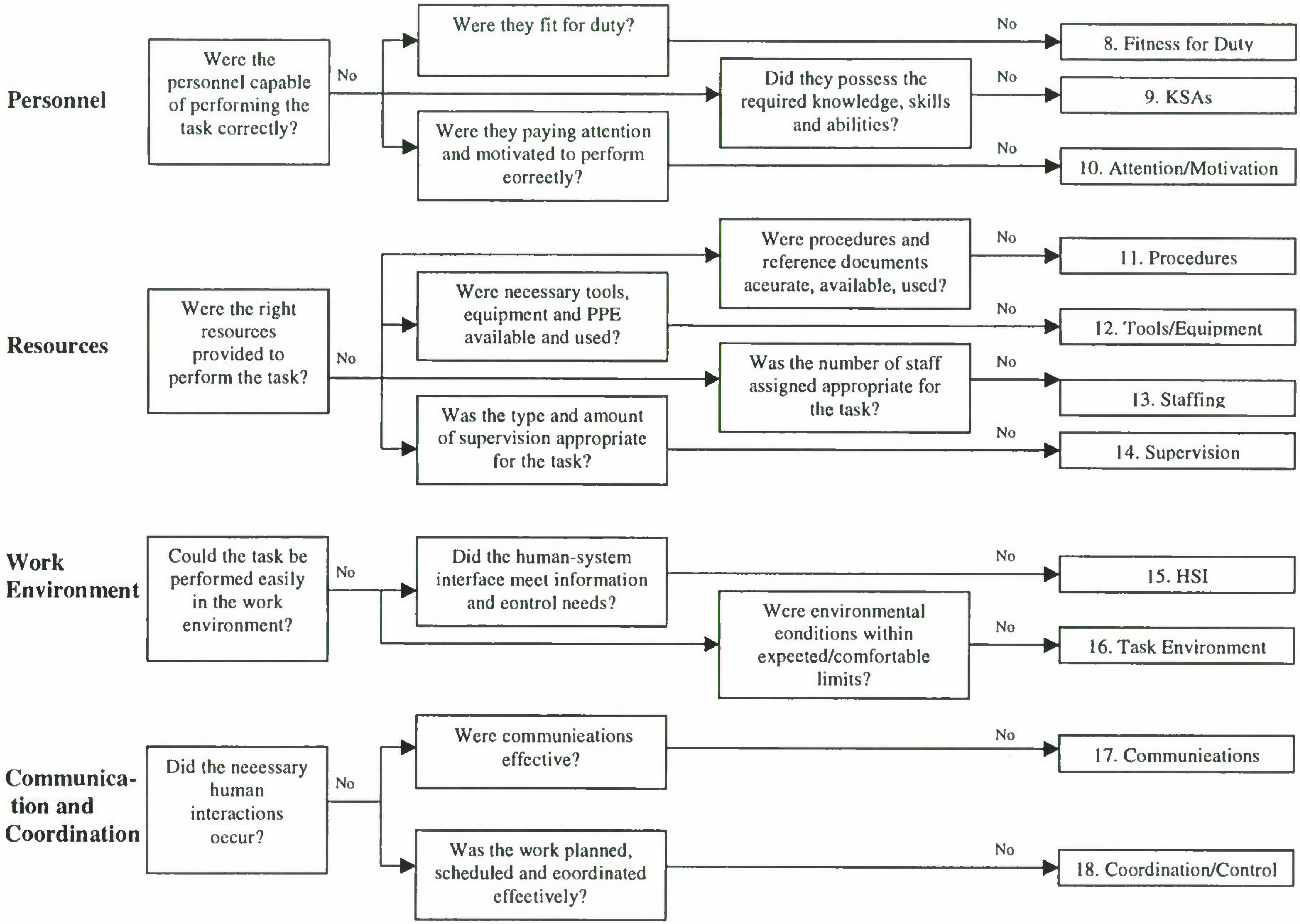


Figure 7-1 The HPEP Cause Tree

8 FITNESS FOR DUTY

8.1 ERRORS RELATED TO FITNESS FOR DUTY

Successful task performance requires that the capabilities workers bring to the task fall within an expected range. **Impairment**, or a reduction in an individual's mental or physical capabilities due to substance abuse, fatigue, illness or stress, increases the likelihood of errors. Types of possible impairments and their likely consequences for task performance are discussed below.

8.1.1 Drug and Alcohol Use

The use of some drugs and alcohol on the job or within several hours of reporting to work may adversely impact human performance. Extensive information about the effects of different drugs on task performance, including prescription and over-the-counter (OTC) drugs, has been published elsewhere (see Section 8.4 of this Module below). This information is briefly summarized here.

8.1.1.1 Marijuana

The use of marijuana has several effects that may adversely impact task performance. Marijuana use decreases the ability to process both auditory and visual stimuli, so may affect, for example, an individual's ability to read and follow procedures correctly or to correctly process verbal instructions. It also reduces an individual's attention span. Other effects include impaired social behavior and reduced retention and recall of information. Marijuana use also affects motor performance. It slows reaction time, decreases motor steadiness and manual dexterity, and reduces eye-hand coordination.

8.1.1.2 Stimulants

Drugs that are stimulants include caffeine, cocaine and amphetamines. Some OTC medications also contain stimulants, such as pseudophedrine, which is commonly used in cold and allergy medications. In small amounts, stimulants generally improve both cognitive and motor performance. For example, attention span is increased, vigilance is improved and reaction time is faster. Larger doses or chronic use adversely affect performance in all areas.

8.1.1.3 Depressants

Central nervous system depressants include the opiates, barbiturates, sedatives, the minor tranquilizers and alcohol. In general, higher doses are associated with significant cognitive and motor performance impairments. At lower doses, the effects depend upon the specific drug used, body weight and the extent to which the user has become habituated to it. For example, eye-hand coordination and performance of complex tasks will be adversely affected by barbiturate use, but typically are not affected by the minor tranquilizers. Use of drugs in this class will often cause drowsiness when they are first taken, but this effect decreases with continued use. Depressants cause disruptions in auditory and visual information processing, impair learning and recall, and reduce attention span.

8.1.1.4 Hallucinogens

Hallucinogens, by definition, are drugs that distort sensory perception, thought processes and behavior. There are four subclasses: anticholinergics (these are rare), catechols (e.g., peyote, mescaline, MDA), indoles (e.g., LSD, psilocybin), and anaesthetics (e.g., PCP). The anticholinergics are highly toxic and not of concern in the workplace. The catechols distort perception of light, color, space and shapes, and increase alertness. They are not associated with memory loss, but may cause muscle spasms in large doses. The indoles primarily cause mood and sensory perception changes leading to altered senses of time, space, touch and color. Vision and hearing are impaired and motor functions decline. At higher doses of indoles, the user may experience euphoria, fear, hostility and confusion. Anaesthetics cause confusion, distorted spatial awareness, aggression, trouble breathing and numbed nerves.

8.1.2 Fatigue

Fatigue has been shown to impair both cognitive and motor performance with an important adverse effect on alertness. Fatigue decreases the ability to process complex information such as that presented by unusual plant conditions. In addition, fatigue may increase reaction time, and impair recall and decision-making. As fatigue increases, performance is increasingly impaired and shows greater variability.

There are many factors that may cause fatigue. These include the amount of time spent working on a single task, sleep disorders and deprivation, and the effects of circadian rhythms or their disruption. For example, long periods of time performing a single physical task will cause muscles to become fatigued so that they are less easily controlled and errors are more likely.

Sleep disorders and sleep schedules that do not allow sufficient deep sleep will adversely affect cognitive and motor performance and, over time, individuals will accumulate a "sleep debt." That is, most working-age adults require about eight hours of sleep on a regular schedule to maintain optimum alertness, mood and performance levels. If sleep is ineffective or insufficient, impairments will be seen during the next waking period. If sleep is ineffective or insufficient for an extended period, the impairments will be cumulative.

Task performance and alertness are also affected by circadian rhythms. **Circadian rhythms** are also known as "biological clocks" and are patterns in physiological functioning over the course of a day. Sleepiness, for example, typically is at a peak between 3 a.m. and 5 a.m. with another increase occurring between 3 p.m. and 5 p.m. When an individual's daily schedule is changed by a change in shift schedule or travel to a different time zone, circadian rhythms are disrupted and performance decrements will occur until a new pattern is established.

8.1.3 Emotional Stress

Stress is an internal psychological and physiological response to threatening events or conditions that require unusual changes in behavior or adaptation. The amount of stress an individual experiences in any given context increases when the individual perceives that the demands of the situation are perceived as exceeding his or her capabilities to cope.

Because a stress response depends upon the individual's appraisal of his or her ability to cope with the situation, individuals will differ in the events and conditions that they experience as stressful. Common sources of potential emotional stress include interpersonal conflicts at home or on the job, grief and loss, unpredictability in one's personal or work life, and any events at home or at work that reduce self-esteem.

Stress may impair task performance in several ways. Personnel may become distracted and unable to focus on the task and so commit errors. Or, stress may cause a worker to become too focused on one aspect of a task to the exclusion of others or have difficulty determining when and how to act. Physiological stress responses may also reduce fine motor coordination. If stress persists over a long period of time, it can cause physical and mental illnesses.

Stress may also adversely affect team performance. Team members typically communicate less under stressful conditions and may fail to exchange information needed to succeed at a task. Or, team members may lose sight of team goals and focus instead on their personal goals and needs.

Experience with a stressor reduces the stress response. Successful past experiences in surviving stressful events and conditions increase an individual's confidence in his or her ability to cope, so that less stress is experienced when similar situations are encountered again.

8.1.4 Illness

Physical and mental illnesses may also cause errors. The effects of physical illness on cognitive and motor performance depend upon the nature of the illness itself. Most physical illnesses are accompanied by fatigue. Some may cause stress. Similarly, the effects of mental illnesses depend upon the nature of the illness and the extent to which symptoms are controllable (and are controlled) with medication.

8.1.5 Combinations of Factors

The effects on performance of combinations of these impairment-causing factors may be synergistic and they may also interact with other conditions in the workplace. For example, fatigue may increase the experience of emotional stress. Or, physical illness may reduce an individual's tolerance for environmental conditions, such as heat or noise.

8.2 DIRECT CAUSES OF FITNESS-FOR-DUTY-RELATED ERRORS

A direct cause of an error resulting from personnel impairment describes characteristics of the impairment that caused task performance to fail. There are a number of ways in which impairment may cause or contribute to an error. These include:

> Substance use – Personnel capabilities were reduced by the use of drugs or alcohol prior to or during working hours, resulting in errors.
>
> Excessive consecutive work hours – Personnel became fatigued because of working too many consecutive hours or working too long on the same task. As a result, for example, mental fatigue due to long hours performing a repetitious task without rest breaks caused

a momentary lapse in monitoring of indications with the result that a safety parameter was exceeded.

Inadequate rest – Excessive overtime with insufficient time off-duty created a "sleep debt." As a result, for example, personnel vigilance was reduced and changes to parameters were not detected.

Circadian rhythms – An individual's circadian rhythms were disrupted by scheduled changes, such as shift rotation or jet lag. Or, capabilities were reduced because task performance occurred during a natural "trough" in physiological functioning. As a result, for example, steps were performed incorrectly during a task because the worker did not recall the correct action sequence.

Emotional stress – Events or conditions in an individual's personal or work life affected the individual's task focus or motor coordination.

Illness – Worker capabilities to perform a task were reduced by the symptoms of physical or mental illness that were not controlled by medication. For example, judgment and decision making may be impaired, leading to errors.

Combination of impairments – Combinations of impairing factors reduced worker capabilities, leading to errors.

8.3 PROGRAMMATIC CAUSES OF FITNESS-FOR-DUTY ERRORS

Barriers to fitness-for-duty-related errors include licensee programs for the detection and prevention of potential or actual impairment, as well as the individual responsibility of workers to decline assignments if they are impaired for any reason. The latter barrier is a weak one, however, because humans are generally over-confident of their capabilities when under the influence of drugs or alcohol, or are stressed, fatigued or ill. Other factors that may discourage self-reporting include the fear of losing access authorization, an operating license or extra income from overtime. Licensee programs that may be implicated in errors caused by personnel impairment include:

Access Authorization – This program is responsible for assuring that individuals with access to special nuclear materials are reliable and trustworthy. Psychological examinations and background investigations are two of the techniques used. Weaknesses in this program may allow impaired individuals to have unescorted access to vital areas in a plant.

Fitness-for-Duty – Licensee fitness-for-duty programs are primarily responsible for detecting and preventing impaired personnel from performing tasks that may affect public health and safety. Medical evaluations of personnel, behavioral observation programs, employee assistance programs and drug and alcohol testing are used to detect impairment. Weaknesses in this program may allow impaired personnel to have access to vital areas in a plant where they could commit errors.

Operator Licensing – NRC requirements for obtaining and maintaining an operating license also include medical and psychological examinations to screen for potential health conditions. Weaknesses in this program may set the stage for health conditions to adversely affect an operator's ability to perform his or her tasks.

Overtime Policies and Practices – The NRC issued Generic Letter 82-12 that provides guidance for limiting work hours to reduce on-the-job fatigue and the potential consequences for task performance. Licensee Technical Specifications and administrative procedures also define work-hour limitations. Routine authorization for work hours in excess of those recommended may result in fatigued workers. Further, a practice of excluding training or meetings that occur outside of an individual's normal work schedule from work-hour limitations will also contribute to fatigue.

Shift Scheduling – Shift scheduling may also affect the likelihood that personnel will show performance decrements due to fatigue. A change in the assigned shift or a rotating shift schedule will disrupt circadian rhythms and may increase the likelihood of errors.

Safety Culture – The effectiveness of self-reporting and behavioral observation programs depends greatly upon the safety culture at a site. For example, if self-reporting of impairment or reporting an impairment concern about another staff member consistently results in disciplinary action, then supervisors and workers may be reluctant to report other staff members who appear to be impaired. On the other hand, if individuals who have come to work under some form of stress are treated fairly and with concern, personnel will report more frequently. If the licensee's culture emphasizes safety over other goals, personnel may be willing to turn down overtime and monitor their own fatigue levels, even if turning down the opportunity results in a loss of income.

8.4 ADDITIONAL RESOURCES ON FITNESS FOR DUTY

- *U.S. Code of Federal Regulations*, Part 11, Criteria and procedures for determining eligibility for access to or control over special nuclear material, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- *U.S. Code of Federal Regulations,* Part 26, Fitness for duty programs, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- *U.S. Code of Federal Regulations,* Part 55, Operators licenses, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- *U.S. Code of Federal Regulations,* Part 73, Physical protection of plants and materials, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- U.S. Nuclear Regulatory Commission (1982). *Nuclear power plant staff working hours* (Generic Letter 82-12). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1989). *Fitness for duty in the nuclear power industry: Responses to public comments* (NUREG-1354). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1989). *Fitness for duty in the nuclear power industry: Responses to implementation questions* (NUREG-1385). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1991). *Nuclear plant staff working hours* (Information Notice 91-36). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1998). *Medical evaluation of licensed personnel at nuclear power plants* (Regulatory Guide 1.134, Rev. 3). Washington, DC: U.S. Nuclear Regulatory Commission.

- Baker, T. (1995). *Alertness, performance and off-duty sleep on 8-hour and 12-hour night shifts in a simulated continuous operations control room setting* (NUREG/CR-6046). Washington, DC: U.S. Nuclear Regulatory Commission.

- Barnes, V.E., Fleming, I., Grant, T., Hauth, J., Hendrickson, J., Kono, B., Moore, C., Olson, J. Saari, L., Toquam, J., Wieringa, D., Yost, P., Hendrickson,P., Moon, D and Scott, W. (1988). *Fitness for duty in the nuclear power industry: A review of technical issues* (NUREG/CR-5227). Washington, DC: U.S. Nuclear Regulatory Commission.

- Durbin, N., Moore, C. Grant, T., Fleming, T., Hunt, P., Martin, R. Murphy, S., Hauth, J. Wilson, R., Bittner, A., Bramwell, A., Macauley, J., Olson, J., Terrill, E. and Toquam, J. (1991). *Fitness for duty in the nuclear power industry: A review of the first year of program performance and an update of the technical issues* (NUREG/CR-5784, PNL-7795, BHARC-700/91/025). Washington, DC: U.S. Nuclear Regulatory Commission.

- Durbin, N. and Grant, T. (1996). *Fitness for duty in the nuclear industry: Update of the technical issues 1996* (NUREG/CR-6470, BSRC-700/96/004, PNNL-11134). Washington, DC: U.S. Nuclear Regulatory Commission.

- Moore, C., Barnes, V., Hauth, J., Wilson, R., Fawcett-Long, J., Toquam, J., Baker, K., Wieringa, D., Olson, J., & Christensen, J. (1989). *Fitness for duty in the nuclear power industry: A review of technical issues* (NUREG/CR-5227, Supplement 1, PNL-6652, BHARC-700/88/018). Washington, DC: U.S. Nuclear Regulatory Commission.

9 KNOWLEDGE, SKILLS AND ABILITIES

9.1 KNOWLEDGE, SKILLS AND ABILITIES IN HUMAN PERFORMANCE

Many of the job positions at licensee sites require extensive and specialized KSAs for correct task performance. **Knowledge** is a set of facts, factual information, a method of analysis or the application of methods and facts to successfully perform a task. A **skill** is a motor or mental capability such as the ability to open a valve or operate a controller. **Ability** is the combination of knowledge and skills required to perform a task. **Mastery** is the process of achieving the requisite KSAs to perform a job or task safely and competently.

A KSA deficiency is one of the more frequently identified causes for human error. There are four basic ways in which an error may occur as a result of KSA deficiencies. These are:

- The worker did not receive training and so did not master the requisite KSA(s)
- The worker was trained, but the training did not result in KSA mastery
- The worker was trained and mastered the KSA, but did not retain it over time
- The worker mastered the requisite KSA, but did not apply it to the task.

The potential risk impacts of personnel performing tasks without the requisite KSAs are the basis for NRC and industry efforts to improve training programs. Not all KSA errors are caused by training deficiencies, however. As will be discussed below, a mental lapse or a momentary loss of situational awareness may also cause KSA-related errors. In addition, for some jobs, a certain level of proficiency is expected when personnel are hired into the position or the services of contractors are obtained. In these cases, human resources screening and selection processes or procurement processes for contractor services may play a role in preventing KSA errors.

9.1.1 Systems Approach to Training

Licensee training programs are presently conducted in accordance with the principles of the **systems approach to training** (SAT), which is also called **performance-based training** (PBT). The NRC assures that training is conducted in accordance with 10 CFR 50.120, "Training and Qualification of Nuclear Power Plant Personnel" and 10 CFR 55.4, "Operators Licenses (Definitions)." The systems approach to training means that a training program includes the following five elements:

- Systematic analysis of the jobs to be performed
- Learning objectives derived from the analysis, which describe desired performance after training
- Training design and implementation based on the learning objectives
- Evaluation of trainee mastery of the objectives during training
- Evaluation and revision of the training based on the performance of trained personnel in the job setting.

As noted in the Statements of Consideration for the 1987 amendment to 10 CFR 55.4, a licensee's training program is considered NRC-approved when it is accredited by the National Nuclear Accrediting Board.

There are currently nine licensee training programs subject to accreditation, as follows:

1. Licensed and non-licensed operators
2. Shift supervisor
3. Shift technical advisor
4. Instrument and control technician
5. Electrical maintenance personnel
6. Mechanical maintenance personnel
7. Radiological protection technician
8. Chemistry technician
9. Engineering support personnel

These training programs identify the required KSAs to successfully function in a job. A job is defined by a set of tasks to be mastered by the worker. These tasks are analyzed to identify the KSAs they require. The KSAs are then consolidated into a master taxonomy of KSAs for each job. Learning objectives for training are prepared from the taxonomies. Mastery of the learning objectives equates to mastery of the KSAs and a successful training program assures that each worker is qualified to perform the various tasks that comprise his or her job.

Performance-based training programs were implemented and first accredited during the late 1980s. Most nuclear power plant personnel have been trained under these programs.

9.1.2 Identifying KSAs with Job and Task Analysis

Job and task analysis (JTA) is a systematic method for identifying the KSAs that are required for successful performance of the tasks associated with a job. The JTA is used to identify the tasks for which training is necessary and may be used to identify requirements for personnel screening and selection.

Tasks are analyzed in the JTA based upon their importance, frequency and difficulty.

- An important task is one that is critical to successful job performance. For example, the operator actions that are modeled in plant probabilistic risk assessments are important, so training for mastery is required.
- An infrequently performed task is one that may not be performed often enough for personnel to maintain mastery.
- A difficult task is one that is complex. For example, the task may involve multiple decisions based upon dynamic plant states.

The KSAs required for these tasks are affected by the quality of the procedures that are available and the characteristics of the **human-system interface** (HSI). For example, if controls are easily manipulated and displays easy to understand, then the operator may not need to master a large

body of detailed information to operate the system. Similarly, if the procedures for a task are clearly written and easily understood, then the worker might not need to memorize the exact sequence of actions required to repair a particular component, because the procedure steps will guide the worker through the task.

Changes to equipment, the HSI and the as-written procedures may require an update to the JTA. When equipment design or procedures are changed, training program personnel will reassess the adequacy of the existing KSAs to determine if additional training is required, or whether current training should be revised or deleted. Revisions to existing training programs and new training may also be required as operating experience provides lessons learned. Personnel screening and selection criteria or contractor requirements may also be impacted.

9.1.3 Training

Training to master the KSAs required for a job may be obtained from a variety of sources. Whether the licensee provides the training or it is obtained from other sources (e.g., trade schools, universities, contractor organizations), there are several factors that may result in personnel not mastering the required KSAs for a job. These include course design and delivery methods, course completion, and training frequency.

Course design begins when the learning objectives have been identified. The design process consists of determining the delivery methods (e.g., classroom, simulator, on-the-job training), number of hours required to cover the materials, instructor qualifications and so on. Although some methods, materials and instructors may be more effective or efficient than others, the important issue is that the course content is complete and addresses all of the relevant KSAs, so that the learning objectives are met and the KSAs mastered.

Another determinant of KSA mastery is course completion. Although this factor appears obvious, there are often competing demands on personnel that may pull them out of training at times. As a result, they may miss the instruction related to specific KSAs. Testing may not identify the KSA deficiency because it is impossible to test mastery of all KSAs. Sampling techniques are used to generate examinations. If attendance and participation are not controlled, some personnel may miss training on specific KSAs and testing may not identify the deficiencies before an error is committed.

9.1.4 Testing

Testing is the primary means used to evaluate KSA mastery. In order to assure that personnel are competent to perform their jobs, the testing requirements should be valid for the job. There are three kinds of validity that are important for a mastery test:

- Content validity – the test items are directly related to job performance by ensuring they match the learning objectives and are appropriately weighted
- Operational validity – the test items address the mental and psychomotor activities that are performed on the job

- Discriminate validity – the test items differentiate between workers who have mastered KSAs required to perform the job and those who have not.

Most training programs do not require perfect performance on test items for all KSAs to demonstrate mastery of the subject. As an example, a score of 80% on most components of the test is required in the operator licensing examination process. A score of 100% is not required, in part, because the validity and reliability of test items vary.

The examination process should identify critical tasks, however. For operators, critical tasks are those actions that are so important to safety that a competent operator is expected to correctly perform these tasks every time to demonstrate mastery. Critical tasks typically form a small subset of the overall group of tasks to be mastered for any job. Emphasis on critical tasks and their associated KSAs in training and testing is important to reduce the likelihood of error.

9.1.5 Proficiency Training

Another factor affecting KSA mastery is forgetting. An individual's ability to perform a task will degrade over time unless the relevant KSAs are refreshed. Proficiency training (i.e., refresher) will be required for some tasks to maintain the level of mastery that was demonstrated following initial training. One function of training programs is to identify those tasks that require proficiency training.

If certain tasks are performed frequently, proficiency training may be unnecessary. By performing a task, personnel practice the task and obtain feedback regarding successful task mastery. Task performance refreshes the KSAs and successful task performance verifies that proficiency has been maintained.

"Just-in-time" training may be used for infrequently performed and difficult tasks. "Just-in-time" training techniques may include a comprehensive pre-job briefing, practice runs on a mock-up or a simulator familiarization session. Determination of the periodicity required to refresh KSAs is part of the design of the training and requalification program, although actual "just-in-time" training may be triggered and administered by a different process, such as work planning and control.

9.1.6 Training Evaluation and Revision

An important aspect of a performance-based training system is the constant evaluation and revision of the training program. This mechanism assures that changes in plant configuration, equipment modifications, procedural changes and lessons learned from operating experience are included in learning objectives and addressed in training program design. An effective training program is dynamic as the plant organization changes and learns. If the training program ceases to capture changes in the plant and industry, training will not provide the necessary KSAs to assure successful task performance.

9.1.7 Cognitive Errors: Loss of Situational Awareness and Mental Lapses

Two fundamental sources of human error that are not associated with KSA mastery are a loss of situational awareness and a mental lapse. A loss of situational awareness or a mental lapse occurs when personnel have previously demonstrated mastery of a KSA but cannot recall it at the required time to prevent an error. An example would be failure to trip a pump when pressure reached a certain value. If the operator did not recognize that pressure had reached that value, the problem was caused by a loss of situational awareness. If the operator recognized that pressure had reached the pump trip criterion but still did not trip the pump, the problem would be a mental lapse. In each case, if the operator had been directly asked when he or she needed to trip the pump, the operator would have correctly responded, "when pressure reached the trip criterion."

9.1.7.1 Loss of Situational Awareness

Loss of situational awareness occurs when a worker does not recognize that a certain KSA applies to the task that he or she is performing. The worker has mastered the KSA and, if asked in a different setting, would be able to demonstrate this mastery. There are four elements required for a finding of a loss of situational awareness:

1. The KSA was essential for satisfactory task performance
2. The individual received training to adequately complete the task
3. The individual mastered the KSA required for task performance
4. The individual did not recognize that the KSA was applicable to the task.

There are several methods available to prevent the likelihood of errors due to a loss of situational awareness. Situational awareness can be improved through "just-in-time training" that focuses on "what-if" scenarios for events that are pre-planned. This allows the individual to think through the various situations that may be encountered during the work activity. Emphasizing rule-based precautions during training may also be helpful (e.g., "Always check Tech Specs whenever any component is declared inoperable"), but will not prevent all losses of situational awareness. Placing the staff member into the situation in which a KSA will be applied, such as a simulator, is also useful in preventing a loss of situational awareness. However, there are so many potential event paths in a nuclear power plant that it is unlikely that simulator-based training can address every possible situation.

The most effective corrective actions to enhance situational awareness for unplanned events are to ensure that prompts or reminders are included in job performance aids. This type of support may include:

- Adding notes or cautions to procedures
- Adding annunciators and alarms that call attention to equipment conditions
- Eliminating or conditionally suppressing unnecessary annunciators that may overwhelm operators during events
- Improving the human-system interface.

9.1.7.2 Mental Lapse

Another source of error is the **mental lapse**, or a momentary lapse in recall for the correct KSA when it is required. Lapses may be random, or may be related to performance shaping factors, such as fatigue, environmental conditions or stress. Often, the lapse occurs because the individual becomes distracted or unfocused. For example, an individual may have been working through one procedure when the task was interrupted by the need to implement a higher priority procedure. The staff member may have intended to complete the initial procedure, but was distracted by the other, higher priority activities and did not remember to return to the first procedure.

Mental lapses are identified when the following four conditions are met:

1. The KSA was essential for satisfactory task performance
2. The individual received training to adequately complete the task
3. The individual previously demonstrated mastery of the KSA(s) required to complete the task
4. The individual did not recall the KSA(s) when required.

Although training programs cannot prevent mental lapses, personnel can be trained to recognize the warning signs of conditions that may increase the likelihood of a lapse and use various strategies to minimize their occurrence. These strategies may include self-checking programs or stress management techniques.

Reducing or eliminating the performance-shaping factors that momentarily distract or overload cognitive processes may also reduce the likelihood of mental lapses. Corrective actions to minimize or eliminate the performance-shaping factors that caused a lapse will be more effective than remedial training on the KSA, given that the individual has already mastered it.

9.1.8 Personnel Selection and Contracting

Licensees often hire new staff, promote staff to new positions, or augment the existing staff with contractor personnel. Personnel selection processes identify the best-qualified individual for a job using several different methods, which typically include an evaluation of previous job experience, education and training. Personality, ability and proficiency tests may also be administered. These methods are intended to ensure that new hires and the staff who are promoted either possess the KSAs required for the job or have the ability to benefit from training for the job. Procurement processes specify the qualifications that contractor personnel are required to have, although licensees may also provide site-specific training to contractor personnel. Weaknesses in the personnel selection and procurement processes may result in work being performed by individuals who have not mastered the necessary KSAs for the task and so lead to errors.

9.2 DIRECT CAUSES OF KSA-RELATED ERRORS

A direct cause of a KSA error describes the reason that the requisite KSA was not applied to task performance. The direct cause of the error may be:

> No KSA – The worker did not possess the KSA required for successful task performance. For example, certain skills were required to use a particular type of self-contained breathing apparatus (SCBA) but the worker did not possess those skills. As a result, the individual was exposed to airborne contamination because the SCBA did not fit properly.
>
> Inadequate mastery - The individual had not mastered the KSA. In this case, the individual had received some form of training, but it was inadequate. For example, a maintenance technician was required to review a new revision to a procedure on her own time. She completed the review, but when it was time to use the procedure, she found that certain steps in the procedure did not make sense to her and she was unable to follow it. As a result, she took incorrect actions.
>
> Inadequate retention – The individual had mastered the KSA but had forgotten how to perform important components of the task, and so, for example, performed steps out of sequence.
>
> Loss of situational awareness - The individual had mastered the KSA but did not recognize the KSA applied to the current situation and so committed an error. For example, a unit supervisor had mastered knowledge regarding the conditions under which it is necessary to post a fire watch, but failed to recognize that a fire watch was required for a particular welding job. As a result, sparks from the welding task caused a small fire.
>
> Mental lapse – The individual had mastered the KSA but failed to recall it and so did not apply it to performing the task. For example, a security guard became distracted by an incident that was being discussed over the radio and so failed to check that a door was securely locked.

9.3 PROGRAMMATIC CAUSES OF KSA-RELATED ERRORS

The training program is responsible for assuring that personnel master the necessary KSAs to perform their tasks. NUREG-1220, Training Review Criteria and Procedures, provides detailed review criteria for assessing training program effectiveness. Several key training program weaknesses are also described here. In addition, other licensee programs or processes that may cause or contribute to KSA-related errors are also listed.

9.3.1 Training Program Weaknesses

> Job and Task Analysis – The JTA did not identify and characterize all of the important KSAs for a job position. As a result, training did not address them and workers were not prepared to perform some tasks correctly. For example, operators violated Technical

Specifications because they had not been trained to understand their applicability to the current situation.

Training Design and Delivery – Training was provided but the design and delivery did not assure KSA mastery. For example, the course content may not have addressed all of the important KSAs for the job, course delivery methods may have been inappropriate for the KSA (e.g., classroom lectures to teach a skill with no opportunity to practice), or the instructors were not qualified to teach the course.

Training Completion – Student attendance and participation were not managed. As a result, an individual or group of workers missed instruction related to important KSAs, did not master them and could not perform the task correctly when required.

Testing – KSA mastery was not evaluated or testing was invalid. As a result, students who had not mastered important KSAs were not detected and so were allowed to perform tasks for which they were not qualified.

Frequency – Proficiency training was not provided or was not provided with sufficient frequency. As a result, KSA mastery degraded and personnel could no longer perform some tasks correctly.

Evaluation and Revision – Lessons learned related to training weaknesses were not communicated or tracked and so training was not revised to address them. Or, changes in plant equipment, work practices and requirements did not result in training revisions. As a result, some staff's KSAs were incomplete or inaccurate.

9.3.2 Other Programmatic Weaknesses

Human Resources – Personnel selection processes did not ensure that new hires or newly promoted individuals had mastered the KSAs required for the job. As a result, some staff did not possess the KSAs to perform effectively.

Procurement – Licensee processes for bringing contractor personnel on-site did not assure that the contractors had mastered the KSAs required for the job.

Work Planning and Control – The work planning and control process did not assign qualified individuals to the task. As a result, personnel who had not mastered the KSAs required performed a task and committed errors.

Shift Staffing – An inadequate number of qualified personnel were assigned to each shift. As a result, planned work could not be executed or unplanned conditions or events could not be managed.

Human Factors Engineering – Procedures, equipment labeling, and human-system interfaces were inadequate to assist personnel in maintaining situational awareness. As a result, workers were unable to complete a repair task because the combination of

inadequate training with poor procedures and labeling prevented them from locating the component on which the task was to be performed.

Industrial Hygiene and Radiation Protection – Weaknesses in these programs may result in workers performing tasks under environmental conditions that promote errors. For example, excessive noise distracted staff from performing their tasks, leading to a mental lapse.

9.4 ADDITIONAL RESOURCES ON KSAs AND TRAINING

- *U.S. Code of Federal Regulations,* Part 50.120, Training and qualification of nuclear power plant personnel, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- *U.S. Code of Federal Regulations,* Part 55.4, Operators licenses (definitions), Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- U.S. Nuclear Regulatory Commission (2000). *Qualification and training of personnel for nuclear power plants* (Regulatory Guide 1.8, Rev. 3). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1999). *Operator licensing examination standards for power reactors* (NUREG-1021). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1998). *Knowledge and abilities catalog for nuclear power plant operators: Pressurized water reactors* (NUREG-1122, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1998). *Knowledge and abilities catalog for nuclear power plant operators: Boiling water reactors* (NUREG-1123, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1996). *Nuclear power plant simulation facilities for use in operator license examinations* (Regulatory Guide 1.149, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1993). *Training review criteria and procedures* (NUREG-1220, Rev.1). Washington, DC: U.S. Nuclear Regulatory Commission.

10 ATTENTION AND MOTIVATON

10.1 ATTENTION AND MOTIVATION IN HUMAN PERFORMANCE

Attention and motivation are often identified as causes for error. "Inattention to detail" and "complacency," for example, are frequently cited as causal factors in licensee problem reports. The evidence supporting these conclusions is often weak, however.

Determining the role of attention or motivation in a human error is difficult outside of a laboratory or simulator setting. Attention and motivation are internal states that cannot be measured directly. In the laboratory, the experimenter can use sensitive instruments to track eye movements and record focus times as measures of attention, for example, or can establish control over the incentives presented to subjects to manipulate motivation levels. Recordings of workers "thinking aloud" as they perform tasks also provide insights into attention and motivation. In an investigation, however, real-time, objective measures of attention or motivation cannot be obtained because the investigation necessarily occurs after the fact. As a result, the investigator must rely on self-reports and inference, which are subject to the biases and inaccuracies discussed in Section 3.

Attributing causality to workers' attention, attitudes, motivations or traits may be common because it is consistent with the "fundamental attribution error." As mentioned in Section 3, this "error" is a natural human tendency in how we explain another's behavior and appears to be "hard-wired" into the human perceptual system. In the absence of compelling evidence that some characteristic of the work environment affected the workers' actions, investigators may resort to this "default" explanation and conclude that the workers were not paying attention or lacked the motivation to perform their work correctly. In reviewing a licensee problem report that cites attention and motivation as causal factors, it may be necessary for NRC inspectors to carefully assess the evidence provided to ensure that it supports the conclusions.

10.1.1 Attention

The term, "**cognition**," refers to how people attend to and process information in making decisions and performing tasks. A useful description of the cognitive processes involved in task performance can be found in NUREG/CR-6126, "Cognitive Skill Training for Nuclear Power Plant Operational Decision Making," and is summarized here.

The information processing required for task performance can be broken down into four stages. These are (1) detection and monitoring, (2) situation assessment, (3) planning, and (4) execution.

In the detection and monitoring stage, the individual seeks out information that is relevant to the task, such as reading gauges, or receives it from signals and cues in the environment that draw attention to salient information, such as alarms activating. The information that is sought is determined by the individual's knowledge of what information is needed or by procedures and

other task demands. The signals and cues provided by the environment may be relevant to the task, such as alarms, or irrelevant, such as a thunderclap.

Numerous errors are possible at this first processing stage. For example, an individual may only seek some information and ignore other relevant information. Or, the worker may be distracted and fail to monitor important indications. Or, there may be too many signals received from the environment at one time and the individual misses important information.

In the situation assessment stage, the individual uses the information gathered from detection and monitoring and his or her knowledge to develop a coherent explanation of the information received. This explanation is formed into a **mental representation** of plant state, in the case of operators, or equipment status, for maintenance or instrumentation and control technicians. This mental representation is used to generate expectations about other plant or equipment parameters, expectations about future consequences, and explanations of what has been observed, as well as to identify unusual conditions and anticipate potential problems.

Errors during the situation assessment stage arise due to inaccuracies in the mental representation that is formed. For example, the representation may be incomplete, if relevant information was not detected during the initial stage. Or, the information received may be interpreted incorrectly. Or, the knowledge that is incorporated into the representation may be incomplete or inaccurate. In some cases, a situation may be too complex for an operator to be able to form an accurate mental representation.

In the response planning stage, the individual chooses a course of action based upon the situation assessment. Response planning involves establishing goals, generating an action plan, monitoring the effectiveness of the plan in achieving the goals, filling in gaps in the plan and adapting it as the situation changes or feedback is received on its effectiveness.

Errors may also occur during any of the response-planning activities. For example, the goals that are established may be incorrect because the situation assessment was inaccurate. The procedure selected for use may be the wrong one for the situation. Or, unexpected events may occur that are not detected, so the plan is not corrected.

Finally, in the execution phase, plans are implemented to achieve the task goals. Plan execution will typically require prioritization of actions, and the allocation of personnel resources and coordination, whenever more than one individual is involved in the task. During the execution phase, the achievement of subgoals is monitored and adjustments may be required.

Errors also occur during plan execution. For example, an individual may forget to take a required action or fail to detect and correct an error that is made.

A key contributor to information-processing errors is the limited capacity of working memory. Long-term memory, where knowledge is stored, is virtually unlimited. But research has shown that working memory can hold and manipulate only about seven items at one time. As a result, information that exceeds working memory capacity may be displaced or lost.

Another contributor to information-processing errors is habit. When a behavior has been practiced or executed many times, it becomes automatic. That is, the need to pay attention to executing the behavior and to exert conscious control over actions is reduced. The benefit of habits is that they reduce the burden on working memory. The disadvantage is that a habit may intrude on performing a new or different task where the habitual behavior is unwanted.

10.1.2 Motivation

Work motivation has been defined as "the conditions responsible for variations in the intensity, quality, and direction of ongoing behavior." Intensity refers to how hard personnel work and how productively work hours are used. Quality refers to both the manner in which work is performed (e.g., safely, conscientiously) and the extent to which work products meet expectations. The direction of work behavior is determined by the values, needs and expectations that personnel bring to the job and the individual's interpretation of the organization's values, reward structures and the goals that are communicated.

Personnel generally require more than a paycheck from their jobs to sustain motivation. Other job characteristics, such as opportunities to maintain and enhance self-esteem, to meet social needs and to grow professionally, have also been shown to be important. In fact, the highest levels of work motivation are found when the organization's and individual's values, needs, expectations and goals are congruent, so that the organization fosters the individual's ability to meet personal needs and goals on the job.

It is important to note, however, that high levels of motivation do not always translate into error-free performance. There are many prerequisites that must be met in a work environment before motivation has much effect. For example, motivation to perform a task correctly is of little value without the knowledge of how to do it. Motivation to perform work safely will not ensure safe performance if the potential risks associated with the work activity and methods to minimize or avoid them are not known. Motivation to perform work in accordance with procedures will be stymied if the procedures for a task are out-of-date, do not apply to current plant status, or cannot be used in the work environment. Motivation to use the required **personal protective equipment** (PPE) or tools and equipment for a job will not ensure safe performance if the necessary PPE, tools and equipment are not available. A key issue for NRC inspectors who are reviewing an investigation in which motivation has been cited as a cause, then, is to rule out other causes for error that may have made worker motivation irrelevant.

One way in which high levels of motivation may reduce errors is that motivated personnel may be more likely to take responsibility for bringing attention to any barriers to correct task performance that they encounter and to fixing those that are within their span of control. But, if the problems identified are not within the workers' span of control and are not addressed by the organization, high levels of motivation may also lead personnel to develop workarounds to get work done despite the barriers. Or, motivation may be decreased and workers become disaffected, if concerns and problems are repeatedly raised but not addressed.

An important source of motivational errors is in defining the goals to be accomplished in task performance. Supervision plays a key role in establishing and communicating the goals to be

met in a work activity. Section 14 discusses the effects of supervisory direction, oversight and leadership on motivation.

Peers may also influence motivation. Crosschecking may detect and correct errors that occur. Peer group norms as they apply to work intensity and quality may also affect individual motivation. Behavior-based safety programs include peer observation and feedback to reduce unsafe acts, although these programs are controversial because of their perceived emphasis on "fixing the worker" rather than "fixing the work environment."

10.2 DIRECT CAUSES OF ATTENTION AND MOTIVATION ERRORS

A direct cause of an attention and motivation error describes the characteristics of a worker's internal state that caused or contributed to an error. Specific examples of errors that may be due to attention and motivation are presented below.

10.2.1 Detection and Monitoring

Information not detected – Task-relevant information was available, but it was not detected. For example, a conversation between an operator and a security guard distracted the operator on her rounds and she failed to detect that a pipe was leaking.

Information discounted – Task-relevant information was available, but it was ignored or interpreted incorrectly. For example, an operator may mentally adjust a reading from an instrument that typically reads high, when the instrument was recently re-calibrated and is reading correctly.

Information lost – Task-relevant information was detected, but was not recalled when needed. For example, an operator may have taken a reading on an instrument, but did not write it down, and so did not remember the earlier reading when he or she checked it again, and failed to detect a trend.

10.2.2 Situation Assessment

Assessment incomplete – Errors were committed because the situation was assessed incompletely due, for example, to incomplete information or the inability to interpret and analyze the information available because of time constraints. As a result, for example, the crew did not recognize that they had entered a Limiting Condition for Operation.

Assessment inaccurate – Errors were committed because the situation assessment was incorrect. The information on which the assessment was based may have been inaccurate, for example, or personnel may have misinterpreted the information received. Or, personnel may not have possessed the knowledge required to assess the situation accurately (refer to Section 9, Knowledge, Skills and Abilities).

10.2.3 Response Planning

Plan incorrect – Errors were committed because, for example, the plan was incomplete or could not be implemented as intended under current plant conditions. For example, workers assigned to a preventative maintenance task were unable to complete it because a control room operator recognized that taking the component out of service would have conflicted with other plant activities.

Plan not modified – Errors occurred because circumstances changed and the plan was no longer appropriate for the circumstances. For example, a construction task could not be completed when an electrical conduit that was not on the drawings was discovered.

10.2.4 Execution

Slip – An error occurred because an unintended action was taken. For example, a technician placed a switch in the OFF position when he had intended to place it in AUTO.

Lapse – An error occurred because the required action was momentarily lost from working memory. As a result, the action was not performed or was performed incorrectly.

Intrusion – An error occurred because an overlearned sequence of actions was performed without conscious control and the habit was inappropriate for the circumstances. For example, personnel risked exposure to hazardous fumes when they followed their usual path to the break room, which required them to pass through a locked door. When they unlocked the door, the fumes reminded them that the room they were about to enter was the site of a recent chemical spill that had not yet been contained.

10.2.5 Motivation

Expectations – Management expectations regarding productivity, quality workmanship and safety were not effectively communicated to personnel and examples of the desired behaviors were not provided. As a result, personnel may have been confused or misinterpreted expectations so that their decisions and actions deviated from what was desired.

Reward structure – The desired behaviors with regard to productivity, quality workmanship and safety were not appropriately rewarded. As a result, individuals' motivation to perform to expectations was decreased, leading to errors.

Feedback – Personnel did not raise concerns or identify barriers to effective performance with the result that errors occurred. Concerns were not raised, for example, due to a perception that nothing would be done to correct the problems or that personnel would be punished for raising concerns.

Workarounds – Concerns were raised and barriers to effective performance were identified, but not corrected. As a result, personnel developed unauthorized and unanalyzed work practices to accomplish tasks and the workarounds resulted in errors. Or, management authorized the workaround because a repair would be too expensive, leading to errors.

Peers – Errors were committed because crosschecking was not performed or peer influence adversely affected productivity, quality workmanship or safety behavior. For example, a staff member who consistently wore hearing protection where required was ridiculed by other staff for doing so.

10.3 PROGRAMMATIC CAUSES OF ATTENTION AND MOTIVATION ERRORS

Many licensee programs, policies and practices are intended to reduce errors associated with attention and motivation. Some programs directly focus on these potential causes and contributors to error, such as the **human factors engineering** program at a site or a behavior-based safety program. Others may indirectly affect attention and motivation during task performance. Licensee programs that may be implicated in errors caused by attention or motivation include:

Human Factors Engineering – Weaknesses in the design of human-system interfaces, for example, may make it difficult for personnel to detect changes in important parameters or to interpret the information displayed correctly. Difficult-to-use human-system interfaces also may frustrate personnel and inadvertently communicate a management message that accurate, timely human performance is not important.

Procedures – Accurate, accessible and usable procedures also play an important role in directing attention, assisting in the development of an accurate situation assessment and in developing and executing response plans. For example, the entry conditions to operating procedures assist personnel to assess the situation accurately. If entry conditions and prerequisites are not provided, personnel are more likely to miss relevant information about the situation and execute an incorrect response plan.

Training – Because knowledge guides information processing at every stage, weaknesses in the training program may have a key effect on the likelihood of attention-related errors. A programmatic weakness in ensuring proficiency training, for example, may prevent personnel from maintaining mastery of the knowledge required to develop an accurate situation assessment or develop effective response plans for tasks that are infrequently performed.

Human Resources – Personnel selection processes play a role in ensuring that staff is qualified (i.e., possess the KSAs required for the job). Weaknesses in the personnel job performance evaluation and reward systems also may fail to communicate management expectations or may reward behavior that does not meets those expectations. If

disciplinary actions are not perceived as being administered lawfully and fairly, employee motivation to work productively and safely may be reduced.

Supervision – Supervision communicates and reinforces management expectations and establishes goals and requirements for task performance. Supervisory oversight may increase motivation to perform in accordance with expectations as well as detect and correct any errors that occur. Weaknesses in supervision, for example, may cause staff to choose production over safety goals in their work or to tolerate workarounds that may lead to errors.

Problem Identification/Resolution – Licensee programs for reporting, documenting and resolving barriers to effective performance maintain staff motivation levels when problem reports result in elimination or mitigation of the barriers. Weaknesses in these programs may not only frustrate personnel, but also encourage the development of workarounds that may lead to errors.

Employee Concerns – Employee concerns programs provide another avenue for personnel to raise safety issues. Weaknesses in the employee concerns program will discourage personnel from raising problems when they fear adverse consequences and will call stated management expectations into question, resulting in lower compliance.

Behavioral Safety – Behavioral safety programs focus on identifying and correcting work behaviors that may result in adverse consequences through behavioral observation and feedback from supervisors and peers. Some programs also emphasize self-checking, such as the Institute for Nuclear Power Operations' STAR program (stop-think-act-review). Focusing on potentially unsafe acts appears to improve human performance at some sites.

10.4 ADDITIONAL RESOURCES ON ATTENTION AND MOTIVATION

- *U.S. Code of Federal Regulations,* Part 19.20, Employee protection, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- Mumaw, R.J. (1994). *The effects of stress on nuclear power plant operational decision making and training approaches to reduce stress effects* (NUREG/CR-6127). Washington, DC: U.S. Nuclear Regulatory Commission.

- Mumaw, R., Swatzler, D., Roth, E. and Thomas, W. (1994). *Cognitive Skill Training for Nuclear Power Plant Operational Decision Making* (NUREG/CR-6126). Washington, D.C.: U.S. Nuclear Regulatory Commission.

- Roth, E., Mumaw, R. and Lewis, P. (1994). *An Empirical Investigation of Operator Performance in Cognitively Demanding Simulated Emergencies* (NUREG/CR-6208). Washington, D.C.: U.S. Nuclear Regulatory Commission.

- Woods, D., Pople, H.E. and Roth, E.M. (1990). The Cognitive Environment Simulation as a Tool for Modeling Human Performance and Reliability (NUREG/CR-5213, Vols. 1 and 2). Washington DC: U.S. Nuclear Regulatory Commission.

11 PROCEDURES

11.1 PROCEDURE-RELATED ERRORS AND THEIR CAUSES

Procedures are instructions for performing a task. The instructions may be provided in formal written procedures or as hand-written information included in a work package. Procedure-related errors are errors that occur because some characteristic of the procedure caused task performance to fail.

The primary purpose of procedures is to ensure that tasks are performed correctly. Procedures also can document the best way to perform a task, so work is performed more efficiently. Procedures may also serve a record-keeping function to document when and how a task was performed.

Procedures reduce the likelihood of human errors under several conditions. When a task is complex or performed infrequently, even the most experienced workers may forget the steps required or the order in which certain steps must be performed. Procedures can also fill gaps in a worker's knowledge about a task, component or system. Procedures are particularly helpful when plant systems are in an unusual configuration and routine actions that may normally be performed without a procedure can result in adverse consequences.

For procedures to be effective in ensuring that tasks are performed correctly, they must be used. There are a number of reasons that workers may not use procedures:

- Procedures are inaccurate
- Procedures are out of date
- No procedure has been written for the task
- Users cannot find the procedure they want to use
- Users don't need a procedure because the task is simple
- Users need more information than the procedures contain
- Users see procedures as an affront to their skill
- Procedures are difficult to use in the work environment
- Procedures are difficult to understand.

It is important to note that using a procedure introduces an additional task to the work being performed. Using a procedure in a step-by-step manner, and checking off each step as it is performed, may ensure that tasks are performed deliberately and correctly. However, there are many circumstances in a plant in which the physical demands of using a procedure in this way complicates the job and can contribute to the likelihood of errors rather than reducing them. Using a procedure also increases mental demands by requiring that the users read the procedure, comprehend it and then act on what they have understood. When this read-comprehend-act loop is added to the primary tasks that operators must perform during upset conditions (e.g., monitoring and detection, situation assessment, response planning and response implementation), it is particularly important that the procedures are easy to understand and use.

The list of reasons for not using procedures also points out some of the ways in which errors can occur when they are used. For example, if a procedure contains inaccurate instructions or a drawing is out-of-date because a system or component has been modified since the document was written, personnel who use the procedure may take incorrect actions. Or, if a procedure step is written in an ambiguous and confusing manner, workers may try to follow it, but take incorrect actions because they misinterpret a step.

Human performance problems are often erroneously attributed to procedures or a failure to follow procedures. Procedures are frequently identified as a cause for human performance problems because they describe the standards and requirements for task performance, and when task performance fails, there is likely some procedure or policy that appears to have been violated. It may not be the case, however, that an attribute of the procedure, or the lack of a procedure, or the failure to use a procedure or reference document caused the error. Rather, what appears to be a failure to follow the procedure may be a symptom of another underlying cause, such as a training need or inadequate labeling, rather than the result of the procedure's characteristics. It is important, therefore, that the licensee provides evidence linking the human error specifically to characteristics of the document or weaknesses in how it was used when identifying a procedure-related error.

11.2 DIRECT CAUSES OF PROCEDURE-RELATED ERRORS

A direct cause of a procedure-related error describes characteristics of the procedures that caused task performance to fail or how the procedure was used or not used that caused task performance to fail. There are a number of ways in which procedures may cause, contribute to or fail to prevent an error. These include:

11.2.1 No Procedure Used

<u>No procedure</u> - Task performance failed because no procedure was written for the task and the workers' reliance on memory or "skill of the craft" resulted in, for example, forgetting important steps, performing steps out of sequence or taking incorrect actions.

<u>Procedure not available</u> - A procedure for the task existed, but was not used and should have been. For example, a procedure may not be available for a task because it was not included in the work package or the workers were not aware that the document existed and so did not find and use it.

<u>Procedure inconvenient to use</u> - Task performance failed because using a procedure was difficult in the work environment. For example, procedure use may be inconvenient in confined spaces, in contamination zones or when wearing protective equipment.

<u>Procedure too difficult to use</u> - Task performance failed because workers considered the procedure too difficult to use and so did not use it. For example, workers may avoid using procedures that are written in excessive detail or that include what they consider to be unnecessary steps that interfere with performing the task. Or, a procedure may be

written with too little detail for the knowledge levels of the workers, so that they do not understand the procedure or misinterpret it.

Procedure use not required - Task performance failed because an existing procedure was not used. For example, licensee policy may have required that the procedure be reviewed before use or that it be available at the work site, but did not require that the procedure be in-hand and followed step-by-step during task performance.

11.2.2 Wrong Procedure Used

Wrong unit, train, component - Task performance failed because the procedure was not intended for use with the equipment that was being operated or maintained. The wrong procedure may be included in the work package or workers may select the wrong document for use. Or, a procedure may not clearly indicate the equipment to which it applies. In some cases, the wrong procedure may be used because labeling is deficient and the workers cannot verify that the procedure applies.

Wrong revision - Task performance failed because the most recent revision to the procedure was not used. If modifications were made to equipment, but the affected documents were not updated, incorrect instructions in the procedure may cause an error. Or, workers may inadvertently access and use an earlier revision.

Wrong procedure for plant/equipment state - Task performance failed because prerequisites for using the procedure were not met by current equipment or system configuration.

11.2.3 Procedure Used, But Wrong or Incomplete

Typographical error - An error was made because information presented in the procedure was incorrect due to a typographical error. For example, the numbers or letters in equipment identifiers, such as valve names, or required values for instrument readings may be transposed or incomplete.

Facts incorrect - Task performance failed because the instructions or the information presented in procedure steps was incorrect. For example, the procedure may include improper set points or describe actions that cannot be taken under normal conditions of use.

Incomplete - Task performance failed because facts or useful information were omitted from the procedure. For example, the procedure writer may have assumed that workers would know the steps required to prepare for conducting a maintenance activity and so did not include them in the procedure. Or, important cautionary information about how to perform a step was not included in the procedure.

Sequence wrong - Task performance failed because the sequence in which the steps were presented in the procedure was incorrect.

Second checker needed, but absent - Task performance failed because the task was important enough to warrant independent verification that the objective of a task or series of actions was achieved, but verification was not required. As a result, errors were committed during task performance, but not detected and corrected.

No placekeeping - Task performance failed because the procedure did not provide a method for placekeeping. Sign-off spaces next to critical steps or other methods for assisting the user to track progress through the procedure were not used. Omitting a procedure step is the most common consequence of not providing placekeeping aids.

11.2.4 Procedure Used, But Followed Incorrectly

Format confusing - The layout of procedure elements on the page was confusing to workers. For example, cautions or notes were not separated from action steps and highlighted with distinctive formatting. Or, the relationship of steps to substeps or lists was unclear because no indenting was used.

Content confusing - The information presented in the procedure or reference document was confusing to workers. For example, the abbreviations or acronyms used were unfamiliar to the users. Or, short, simple action steps in the imperative voice were not used. Conditional statements (i.e., logic steps used to present decision points in procedures) can be particularly confusing if formal Boolean logic statements are not used. Cross-references to other procedures, to reference documents or to other steps within the same procedure may be confusing and can cause workers to lose track of the sequence in which they are to perform steps.

Graphics confusing - Graphics used in the procedures were confusing to workers. Tables or figures were difficult to read and understand. Or, too many emphasis techniques were used in the procedure text so that unimportant information was highlighted, while important information was not.

11.3 PROGRAMMATIC CAUSES OF PROCEDURE-RELATED ERRORS

Programmatic causes of procedure-related errors are typically found in the licensee's processes for managing the development, use and control of procedures. A number of good practices have been identified to assure that procedures will be effective in preventing errors, many of which are documented in NRC guidance for emergency operating procedures programs. Other programs may also contribute to procedure-related errors.

11.3.1 Procedures Program

The following weaknesses in procedures programs have been shown to result in ineffective procedures:

Multidisciplinary team not used - Development of technically accurate and usable procedures is enhanced by the involvement of a multidisciplinary team. Procedure development teams should include specially trained procedure writers working with

subject matter experts, such as a representative of the intended users and engineers with specific expertise regarding the equipment to be operated or maintained. A single procedure writer working alone may miss important technical information, may use terminology that is unfamiliar to the intended users, or sequence the procedure steps inefficiently. As a result, the procedure may be inaccurate or difficult to comprehend, increasing the likelihood of errors.

Writer's guide - Writers' guides provide information to procedure writers regarding techniques for formatting procedures, presenting different types of content (e.g., action and decision steps) and for developing usable graphics. If a writer's guide is not followed or it is incomplete, the resulting procedures may be difficult to comprehend and follow.

Verification - Procedure verification is a process that provides a final check on the technical accuracy of the procedure steps and on the procedure's compliance with writers' guide requirements. In most plants, an individual who was not involved in authoring the procedure typically verifies that the procedure correctly incorporates information from the technical basis documents and meets the writer's guide requirements. Verification may also involve walking down the procedure at the work site to ensure that equipment identifiers in the procedure match the labels and tags on the equipment, that the procedure can be used under the expected conditions at the work site, that the steps are sequenced correctly and efficiently considering the layout of the worksite, and that the tools list is complete. Procedures that have not been verified are often incomplete, inaccurate and difficult to use.

Validation - Procedure validation is a process to check that the procedure can be used as written. Validation exercises in a control room simulator with crews of operators may be used to validate operating procedures. Maintenance simulators or mock-ups may be used to validate maintenance procedures. Procedures that have not been validated may result in unintended consequences or may not be usable under actual work conditions.

Review and approval - The procedure review and approval process ensures that personnel in all other departments whose work may be affected by the procedure have the opportunity to review it to assure that activities in their departments are not adversely affected. Review and approval should also assure that any other procedures affected by the procedure are identified and modified, if necessary. Out-dated cross-references between procedures are a common source of error. Management reviews of procedures or procedure revisions will ensure that the procedure is consistent with management goals and policies.

Procedure revisions - The procedure program should include a process for reviewing and revising procedures when changes occur at the plant that may affect the technical accuracy or usability of the procedures. For example, if plant equipment is modified, the procedures and drawings that apply to the equipment may require revision. Or, if the knowledge and skills of the workforce change due to new hires, layoffs, an aging and retiring workforce, then the level of detail in the procedures may need to be increased to

better accommodate the new users. Changes in management goals and policies may also require procedures to be revised to ensure they are consistent with new directives. And, if other documents change that are referenced in the procedure, the procedure should be reviewed to determine whether any revisions are required.

11.3.2 Other Programmatic Weaknesses

Training – Coordination between the training and procedures programs is necessary to ensure that user training needs are assessed for a new or revised procedure. Changes to existing training may be necessary to ensure that the users are, at a minimum, familiar with the new or revised procedure and are qualified to use it before the procedure is implemented. Weaknesses in training on a new or revised procedure may

Operating Experience – Lessons learned from users' experiences with the procedures is necessary to ensure that any problems or limitations in procedures are detected and corrected. If operating experience does not lead to timely procedure revisions, personnel may avoid using the procedures or develop workarounds.

Information Management - Technically accurate procedures depend on the availability of up-to-date reference documents, such as vendor manuals, engineering analyses, and drawings. If the reference documents used to develop procedures are incomplete or contain errors, those omissions and errors may be translated into the procedures. A document control process is also necessary to ensure that workers have access to a complete and the most recent revision of the procedure.

Maintenance – Procedures are written on the basis of assumptions about the operability and condition of the equipment to which they apply. If the equipment has not been maintained and is inoperable or in a degraded condition, errors may occur if the procedure is not revised to reflect actual equipment conditions.

11.4 ADDITIONAL RESOURCES ON PROCEDURES

- *U.S. Code of Federal Regulations,* Appendix B to Part 50, *Quality assurance criteria for nuclear power plants and fuel reprocessing plants*, Criterion V, Instructions, procedures and drawings, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- U.S. Nuclear Regulatory Commission (1978). *Quality assurance program requirements (Operation)* (Regulatory Guide 1.33, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1982). *Guidelines for the preparation of emergency operating procedures* (NUREG-0899). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1989). *Lessons learned from the special inspection program for emergency operating procedures* (NUREG-1358). Washington, DC: U.S. Nuclear Regulatory Commission.

- O'Hara, J.M., Higgins, J.C., Stubler, W.F. and Kramer, J. (2000). *Computer-based procedure systems: Technical basis and human factors review guidance* (NUREG/CR-6634). Washington, DC: U.S. Nuclear Regulatory Commission.

- Barnes, V.E., Moore, C.J. Wieringa, D.R., Isakson, C.S., Kono, B.K. and Gruel, R.L. (1989). *Techniques for preparing flowchart-format emergency operating procedures: Vol.s 1 and 2* (NUREG/CR-5228, PNL-6653, BHARC-700/88/017). Washington, DC: U.S. Nuclear Regulatory Commission.

- Morgenstern, M., Barnes, V., McGuire, M., Radford, L. and Wheeler, W. (1985) *Operating procedures in nuclear power plants: Practices and problems* (NUREG/CR-3968, PNL-5648). Washington, DC: U.S. Nuclear Regulatory Commission.

- Morgenstern, M., Barnes, V., Radford, L., Wheeler, W. and Badalamente, R. (1984). *The development, use and control of maintenance procedures in nuclear power plants: Problems and recommendation*s (NUREG/CR-3817, PNL-5121). Washington, DC: U.S. Nuclear Regulatory Commission.

12 TOOLS AND EQUIPMENT

12.1 EFFECTS OF TOOLS AND EQUIPMENT ON HUMAN PERFORMANCE

The design and use of tools, equipment and **personal protective equipment** (PPE) in the workplace are typically considered industrial safety and health issues. But, tools, equipment or PPE may impact risk if they cause or allow personnel to make errors that may affect safety systems.

12.1.1 Tool Design and Use

Tool use is often necessary for work activities at licensee sites. Numerous checklists containing evaluation criteria for tools have been published as a result of increased public concern over workplace injuries, particularly those resulting from repetitive motion (e.g., carpal tunnel syndrome). In general, any tool characteristic that increases the risk of worker injuries will also increase the risk of errors during task performance.

The proper tools for a task depend upon the characteristics of the workplace, the individual workers and the task demands. For example, in confined areas, tools must be small enough to be usable in the workspace available while retaining their functionality. Errors may result if tools do not fit a user's hand size or handedness (i.e., use of a right-handed tool by a left-handed worker), skill levels or strength. Errors are also more likely if the task requires the use of force or repetitive motion in using the tool.

Poorly designed tools, tools that are inappropriate for the workplace, worker or task, or tools that are not maintained may affect human performance in several ways. The primary effect of poorly designed tools is on motor performance. Poorly designed tools may be dropped, cause physical slips and erroneous actions, or lead to fatigued or injured muscles that are more difficult to control. Some tools may interfere with visibility or increase discomfort and cause workers to rush through jobs. Tools that are not maintained will not function as intended and may cause errors when they are used.

12.1.2 Equipment

The use of various types of equipment and machinery necessary to perform some work activities may also cause or contribute to errors. Equipment may be temporary or permanently staged at a worksite. Ladders, scaffolds or lifts may be used for aboveground work. Cranes, trucks, forklifts, loaders, or robots, for example, may be brought to a worksite for some tasks. Some tasks require the temporary deployment of additional lighting, parts, and the electrical cabling to energize necessary machinery. The introduction of equipment and machinery to a worksite may complicate task performance and represents a change. Equipment and machinery may also affect task performance if personnel expect it to be available and it is not, such as a missing ladder that was pre-staged for emergency operations but was removed and used for other purposes.

Aboveground work is particularly hazardous and may have adverse effects on some workers. For example, personnel may experience dizziness, instability or vertigo when working at heights.

These responses may be intensified if the surface on which they are standing moves. Work at any height also introduces the potential for tools and other materials to be dropped, which may damage equipment or personnel below, or create foreign material issues.

Extensive regulations and guidance have been published by the Occupational Safety and Health Administration and other government agencies regarding the safe work practices and design characteristics of equipment that prevent worker injuries and other workplace hazards. In general, the practices and equipment designs necessary to prevent injuries also serve to prevent errors that may impact safe operations.

12.1.3 Personal Protective Equipment

Personal protective equipment is necessary to perform many tasks at licensee sites. Depending upon the type of hazard to which workers may be exposed, PPE may include eye, hand, ear and foot protection, aprons or full suits, such as anti-contamination clothing. Protection from heat stress and cold may be necessary at times, as well as respiratory protection or protection from open flames for hot work. Aboveground work may require safety harnesses.

The design and use of PPE may cause or contribute to errors in several ways. The most important concerns are that PPE may reduce sensory input, limit feedback and impair motor capabilities. For example, darkly tinted safety glasses may hinder vision if used indoors. Gloves reduce fine motor control. Hearing protection may prevent personnel from hearing alarms or verbal communications. Personnel may become entangled in fall protection gear. Some forms of protective clothing may contribute to heat stress, which may affect both cognitive and motor functioning, leading to errors. Combinations of PPE may interact and interfere with performance. Wearing PPE is also often uncomfortable and may distract workers or cause them to hurry through tasks, increasing the potential for errors.

Personal protective equipment that is not maintained properly may also lead to errors. For example, safety glasses and face shields that have become scratched distort or interfere with vision. In general, the use of PPE is the least preferred alternative for protecting workers because of the impacts on performance most types of PPE will have.

12.2 DIRECT CAUSES OF ERRORS RELATED TO TOOLS AND EQUIPMENT

A direct cause of an error related to tools and equipment describes the characteristics of the tools or equipment that caused task performance to fail. There are a number of ways in which the design and use of tools and equipment may impair performance. Examples of these are presented below.

12.2.1 Tools

Tool mismatched to task environment – The tool used for the task was too large, too small or otherwise inappropriate for the work environment. It may have obscured the parts or equipment on which work was being performed, causing errors, or created discomfort.

Tool mismatched to worker – The tool was too large, too small or inappropriate for the worker's physical characteristics, such as hand-size, strength or agility. Some tools require skills to be used. If a worker has not been trained to use the tool or the tool is mismatched to the individual's characteristics, he or she may commit errors by using it improperly, break equipment or become injured.

Tool poorly designed - Poorly designed tools may increase discomfort. Tools that are uncomfortable to use may cause personnel to rush through a task and commit errors. Tools that are poorly designed may also impair motor control and cause errors, such as breaking equipment or applying excessive torque on a screw.

Tool degraded - Tools that are not maintained may not function as intended or in accordance with the workers' expectations. Miscalibrated or broken tools may cause personnel to take incorrect actions or may damage other equipment.

Correct tools not available or used - When special tools have been designed for performing a task, an administrative challenge is created to ensure that they are available at the worksite when needed. If other tools are substituted for the special tool, task performance may be delayed by the workaround or it may not be possible to accomplish the task to specifications.

12.2.2 Equipment

Deployment wrong – Errors occurred because the equipment or machinery was deployed incorrectly. For example, the ground underneath a ladder or scaffolding was uneven, angled or could not support the weight. Or, machinery was deployed too near electrical power lines, possibly resulting in an electrical, or too near overhead obstructions, possibly causing damage to other equipment or injuries to personnel.

Design or construction wrong – Errors occurred because the equipment or machinery was poorly designed or constructed. For example, toeboards were not provided on platforms erected in areas where dropping tools or material could cause harm. Or, the scaffolding materials used were insufficiently sturdy for the weight placed on them.

Used improperly – The equipment or machinery was used in a manner for which it was not designed or not authorized. For example, a load contained too much weight or a crane was used to lift personnel without following proper procedures, increasing the likelihood of equipment damage or injuries.

Not available - Equipment or machinery required to perform a task was not available when needed. Errors may occur if task performance is delayed while personnel search for the required equipment and if other equipment or machinery is substituted for the missing equipment.

12.2.3 Personal Protective Equipment (PPE)

Mismatched to task – Task performance failed because the design or use of the PPE made it more difficult than necessary. For example, work was performed in a high temperature environment with multiple layers of anti-contamination clothing and other PPE, resulting in cognitive impairment due to heat stress. Or, the use of tinted safety glasses indoors impaired vision and prevented a worker from correctly reading a tag.

Mismatched to worker – Task performance failed because ill-fitting PPE caused discomfort and interfered with task performance. For example, gloves that were too large further reduced fine motor control and tactile feedback, leading to errors. Workers were uncomfortable and rushed through tasks, with the result that post-maintenance testing was not completed.

Poorly designed – Task performance failed because required PPE was poorly designed and so was ineffective, allowing workers to be exposed to hazards that cause errors. For example, a poorly designed respirator may allow a worker to be overcome by caustic fumes.

Not used – Task performance failed because PPE was not used when required, with the result that personnel were exposed to hazards that caused injuries and errors. For example, an instrumentation and control technician received an electrical shock, which also destroyed some wiring in the electrical panel.

Not available – Task performance failed because PPE was not available when required. As a result, personnel were unable to complete a surveillance timely and Technical Specifications were violated. Or, respirators were not readily available for emergency use and workers were unable to enter an area to respond.

Used incorrectly – Task performance failed because personnel used the incorrect PPE for a task or used PPE incorrectly. For example, a worker allowed his safety glasses to slide down the bridge of his nose and spilled a caustic chemical when fluid splashed into his eyes.

Degraded – Task performance failed because PPE was not maintained and failed to protect workers from hazards. For example, a degraded respirator allowed an uptake.

Combined – Task performance failed because combinations of PPE were required for a task and interacted to interfere with performance. For example, safety glasses worn under a face shield distorted vision, causing errors.

12.3 PROGRAMMATIC CAUSES FOR ERRORS RELATED TO TOOLS AND EQUIPMENT

Programmatic causes of errors related to tools and equipment are typically found in the licensee's procurement processes, and industrial hygiene, radiation protection and

maintenance programs. Other programs may also be implicated. Common programmatic causes of errors related to tools and equipment include:

Work Planning and Control - Work planning and control processes may fail to identify the tools and equipment needed at the work site. For example, working in a high temperature environment with multiple layers of anti-contamination clothing and other PPE, without assuring adequate body cooling or personnel rotation, may cause cognitive impairment due to heat stress.

Procurement – The licensee's procurement program ensures that the tools, equipment or PPE that are required to perform a work activity have been purchased and meet specifications. For mobile equipment that may be brought to the site, such as cranes, the procurement program is also typically responsible for ensuring that contractor equipment meets requirements and that contractor personnel are qualified to operate the equipment. Weaknesses in the procurement program may lead to the use of inappropriate, uncomfortable or ineffective tools, equipment or PPE.

Industrial Hygiene and Radiation Protection – These licensee programs are responsible for ensuring that the hazards associated with a work activity have been identified, communicated to the workers, and that proper hazard controls are implemented. These programs are also typically responsible for ensuring that PPE is fitted to individual workers. Weaknesses in these programs may not only result in the unnecessary exposure of workers to hazards, but may also set the stage for errors.

Procedures - As part of the licensee's procedure development process, the tools, equipment and PPE required for a work activity should be considered when designing the procedures and defining how they will be used. For example, effective procedures are designed so that their use is compatible with the use of tools, equipment and PPE. Procedures that do not specify the tools, equipment and PPE required to perform a task may cause delays or errors if incorrect tools and equipment are used.

Training – Personnel often need specialized training to use some types of tools, equipment and PPE. If these training needs have not been met, workers may use incorrect tools, equipment or PPE or use them improperly, resulting in errors.

Human Factors Engineering – Requirements for special tools, equipment and PPE should be considered whenever new equipment or systems are installed. As a general rule, engineering controls for hazards are more effective than PPE. The need for special tools or equipment creates an administrative burden and can often be avoided if the potential impacts on human performance are considered during the design stage. Reducing the need for special tools, equipment and PPE reduces opportunities for delays and errors in task performance.

Operating Experience - Reviews of relevant operating experiences from the plant and other facilities with similar work activities may reveal problems associated with tools and equipment as well as solutions to those problems. Weaknesses in the operating experience

program may Personnel may have reported problems with tools and equipment that previously interfered with performance, and further issues may be avoided if the problems are corrected.

Maintenance – Maintenance of tools, equipment and PPE is necessary to ensure that they are in working condition when needed. Inadequate maintenance will allow tools, equipment and PPE to degrade so that they are difficult to use, ineffective or cannot be used.

12.4 ADDITIONAL RESOURCES ON TOOLS AND EQUIPMENT

- U.S. Nuclear Regulatory Commission (1988). *Memorandum of understanding between NRC and OSHA relating to NRC-licensed facilities* (Information Notice 88-100). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1998). *Potential for degradation of the emergency core cooling system and the containment spray system after a loss-of-coolant accident because of construction and protective coating deficiencies and foreign material containment* (Generic Letter 98-04). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1999). *Acceptable programs for respiratory protection* (Regulatory Guide 8.15, Rev. 1). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1996). *Human-system interface design review guideline* (NUREG-0700, Rev. 1, Vol.s 1-3). Washington, DC: U.S. Nuclear Regulatory Commission.

13 STAFFING

13.1 EFFECTS OF STAFFING ON HUMAN PERFORMANCE

Staffing is the process of accessing, maintaining and scheduling personnel resources to accomplish work. An adequately staffed organization ensures that personnel are available with the proper qualifications for both planned and foreseeable unplanned activities. Staffing is a dynamic process in which plant management monitors personnel performance to ensure that overall organizational performance goals are met or exceeded. The result of an effective staffing process is a balance between personnel costs and the achievement of broader organizational goals.

13.1.1 Staffing Requirements

The NRC has established several regulations regarding the staffing of nuclear power plants. Title 10 CFR 50.54(m) establishes the regulatory minimum crew composition for licensed operators. Title 10 CFR 50 Appendix R establishes the requirements for a Fire Brigade. NUREG 0737, "Clarification of TMI Action Plan Requirements," sets the requirement for a Shift Technical Advisor (STA). Each licensee has further established requirements in Technical Specifications or Site Licensee Commitments for a minimum level of shift staffing as well as a general description of the site organization. The regulatory requirements are often lower than the licensee's administrative requirements for minimum shift staffing levels.

NRC Information Notices 91-77 (Shift Staffing at Nuclear Power Plants) and 95-48 (Results of Shift Staffing Study) both stated in part:

> "The number of staff on each shift is expected to be sufficient to accomplish all necessary actions to ensure a safe shutdown of the reactor following an event. Those actions include implementing emergency operating procedures, performing required notifications, establishing and maintaining communications with the NRC and plant management, and any additional duties assigned by the licensee's administrative controls...."

13.1.2 Staffing Decision-Making

Personnel costs comprise a significant proportion of an organization's operating budget. Managing staff size to manage costs is a necessity for any business. There are a number of issues to be addressed when staffing decisions are made. These include the range of expertise required, the number of personnel needed, and the anticipated workload, so that the necessary staff and expertise are available when needed.

13.1.2.1 Range of Expertise

Each organization requires the proper amount and type of expertise to safely and competently operate the plant under a variety of conditions. The term "expertise" includes the attributes of

talent, effectiveness, knowledge, skills, abilities and experience necessary to operate and maintain plant systems, structures and components.

Organizations balance the costs of maintaining full-time expertise on staff with the probability that the expertise can be obtained from outside the organization when the need arises. For example, it may be cost-effective to hire three junior engineers in a discipline for the same costs as two senior engineers, if the normal engineering workload requires three full-time staff. However, complex issues may occasionally arise that junior staff cannot resolve effectively. A lack of access to the expertise of senior personnel could increase the workload, costs, or the likelihood of human errors if, for example, a corrective action developed by junior staff was not the optimum approach.

Another factor that may impact access to expertise is the aging workforce in the nuclear power industry. Many of the individuals who were involved in plant construction and start-up activities are reaching retirement age. As they leave the workforce, these individuals often take with them extensive and irretrievable information about the design, construction, operation and maintenance of the specific systems and components with which they worked over the years. Efforts to document their knowledge and extended turnovers to the junior staff may capture some of the knowledge they have accumulated. It has been the case at times, however, that the knowledge was simply lost, with the result that errors have occurred as junior staff "learn the ropes."

13.1.2.2 Staff Size

The number of individuals who are available to support planned and unplanned activities is a key staffing issue. Organizations must ensure that adequate numbers of personnel are available to accomplish on-going work activities timely and to address the unplanned activities, or plant events, that may occur. On the other hand, too many staff may hamper performance on some tasks. Manpower planning and analyses ensure that the staff size supports human performance.

Surges in workload, such as outages at nuclear power plants, typically require staff augmentation as well as longer work hours for permanent staff. The introduction of contractor personnel or licensee personnel from other sites may increase the likelihood of errors due to unfamiliarity with the plant, its procedures and hardware, for example. Longer work hours have the potential to increase fatigue, which also contributes to the likelihood of error.

A key consideration in establishing the shift schedule is the staff size and composition that would be required to respond to an event during the period in which the Emergency Response Organization is recalled. This period generally lasts for the first hour of the event due to activation and personnel transit time to the site, especially on the back shift. The occurrence of an event typically involves a substantial increase in workload. Insufficient staff to meet the increased demands will exacerbate the **stress** naturally experienced by personnel on-shift at the time an event occurs and increase the potential for errors, as discussed below.

Workload may also be increased by organizational changes. For example, in order to reduce costs, some organizations reorganize and re-assign job responsibilities. Others may implement a local or across-the-board hiring freeze and attractive early retirement packages, to reduce staff

size through attrition. In the absence of careful planning and workload analysis, these efforts to reduce personnel costs may result in an increase in human performance problems. Morale may suffer if personnel are "required to do more with less" and are unable to complete their assigned work on schedule. Or, staff may feel constant pressure to "do more" and so take shortcuts or rush through their tasks, leading to errors. Personnel may find themselves working longer hours over the long-term, which may result in increased fatigue and an increase in the likelihood of errors. And, if the potential loss of expertise associated with buy-out packages for senior staff is not considered, errors may increase as junior staff members assume new responsibilities.

Maintaining a larger staff or assigning more staff to a task does not always improve performance. Organizations can become "bloated" and develop inefficient, bureaucratic work methods if the number of personnel available is greater than the workload. In addition, the assignment of multiple staff to a task may increase task complexity by increasing the amount of communication and coordination required among personnel. For example, some maintenance tasks may require expertise in both mechanical and electrical maintenance. If two specialists are used to perform the task, it is likely that they will need to communicate about the work and coordinate their activities. These ancillary tasks of coordinating and communicating introduce increased opportunities for error. One individual who is qualified in both specialties may be able to perform the task more effectively.

13.1.3 Task Overload

The primary consequence of inadequate shift staffing is **task overload**. Task overload exists when the number of tasks that must be accomplished in a given period of time exceeds the available personnel resources. There are various work management strategies for responding to task overload including:

- task prioritization and deferral or slippage
- increasing the work pace
- task delegation.

These strategies may lead to errors in some circumstances. For example, tasks may be inappropriately deferred so that systems or components are unavailable when needed. Increasing the work pace may lead to shortcuts or errors due to rushing. Task delegation may result in tasks being performed by individuals who do not have the expertise to perform them correctly. Task overload may increase stress, leading to errors.

13.2 DIRECT CAUSES OF STAFFING-RELATED ERRORS

A direct cause of a staffing-related error describes the characteristics of staffing practices that caused or contributed to the error. Examples of direct causes for staffing-related errors are presented below.

> <u>Expertise Not Available</u> – The correct mix of qualified personnel was not available on staff to perform the work. For example, a lack of available expertise resulted in delaying

task performance until a qualified person could be called in, or the task was assigned to a less qualified person who committed an error.

Insufficient Staff Available – Task performance failed because adequate numbers of personnel were not available to perform the work. As a result, work management strategies were employed and the level of stress increased, leading to errors.

Too Many Staff – Task performance failed because too many workers were assigned to the job. As a result, communication and coordination burdens were increased, which increased the opportunity for errors.

13.3 PROGRAMMATIC CAUSES FOR STAFFING-RELATED ERRORS

Programmatic causes of errors related to staffing are typically found in the licensee's business planning and work scheduling programs. Other programs may also be implicated. Common programmatic causes of errors related to staffing include:

Human Resources – Most licensees develop some form of a business plan that defines organizational goals and objectives. Business plans are often used to estimate the resources required to achieve the goals and run the business. Business plans may be used to determine staffing levels for the various parts of the corporate organization, sometimes without manpower planning and analyses of anticipated workload levels. As a result, there may be insufficient staff or staff may not have the required expertise.

Work Planning and Control - The work planning and control system is often used as an integrated scheduling tool to match the workers to support specific jobs. Weaknesses in the work planning and control system may result in the assignment of too few or too many personnel for a job or fail to ensure that only qualified personnel are assigned.

Shift Staffing - All licensees establish a shift staffing policy that defines the minimum required levels of shift personnel. This policy is often integrated with the scheduling of individuals to shifts and overtime management. If these policies are not clearly defined, the lack of clarity can cause staffing deficits that set the stage for human errors.

Training – The training program ensures that personnel are qualified for their jobs and that managers are trained to implement shift staffing and overtime policies. Sometimes, these policies may be difficult to understand. Weaknesses in the training program may fail to assure that supervisory personnel understand staffing requirements, for example.

Human Factors Engineering – The human factors engineering program ensures that the number of personnel required and the expertise they will need are considered whenever new equipment or systems are installed. Weaknesses in this program may result in too few or too many personnel assigned to a job or in the installation of systems that staff cannot operate with their existing KSAs.

13.4 ADDITIONAL RESOURCES ON STAFFING

- *U.S. Code of Federal Regulations,* Part 50.54(m), Conditions of licenses, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- *U.S. Code of Federal Regulations,* Appendix R to Part 50, *Quality assurance criteria for nuclear power plants and fuel reprocessing plants,* Criterion III (H), Fire brigade, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

- U.S. Nuclear Regulatory Commission (1995). *Results of shift staffing study* (Information Notice 95-48). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1991). *Shift staffing at nuclear power plants* (Information Notice 91-77). Washington, DC: U.S. Nuclear Regulatory Commission.

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14 SUPERVISION

14.1 SUPERVISION AND HUMAN PERFORMANCE

Supervision is the process by which work is directed and overseen by first-line management. Successful supervision requires a combination of leadership skills and technical competence. Supervision differs from peer checking or quality control because a supervisor has line management responsibility for the worker(s) as well as responsibility for the work activity.

Supervision is more than the moment-to-moment direction of a work activity. Successful supervision requires the assessment and shaping of worker attitudes and motivation, communication and implementation of management expectations for performing work, the assignment of the best-qualified workers to various tasks, as well as the technical competence to identify incorrect actions and stop improper activities before an error is committed. Effective supervision involves directing the work, overseeing how it is performed and leadership.

14.1.1 Direction

Directing work activities includes defining desired outcomes, planning, organizing and controlling work, and problem solving. Direction occurs during preparation for a task and during task performance.

The role of supervision during work preparation is to assure that the personnel who will be performing the task have the information and resources required to perform effectively. These resources include knowledge of the goal(s) of the work activity as well as management expectations for how the work is to be performed. Goals and expectations are often communicated during pre-job walkthroughs of the task environment and in pre-job briefings. Supervisors may also be required to ensure that the personnel assigned to perform the task are qualified, that the necessary tools and equipment are available, and that procedures and other instructions for performing the task, such as those included in a work package, are complete and understood by the workers. Supervisors may be responsible for verifying that the prerequisite conditions for tagging equipment out-of-service are met before the work begins and for obtaining authorization to start the task.

Supervisors act as a resource during performance of the work activity. Workers may call on them to answer questions, provide instructions in ambiguous or unanticipated situations and problem-solve. Supervisors also are the interface between the work group performing the task and other parts of the organization, including more senior management. Interface responsibilities may include requesting additional resources to complete the task, obtaining authorization to change the work plan or stopping work if unexpected conditions arise.
Personnel generally respond well to a supervisor when they have confidence in his or her technical background. Conversely, a supervisor with inadequate technical qualifications can foster resentment and degrade team performance because the supervisor cannot fulfill some of his or her responsibilities to the team. A first-line supervisor who is not technically competent may direct the work incorrectly.

Errors due to poor supervisory direction may arise when any of the supervisor's responsibilities for directing the work are not met. For example, on a task that will be repeated several times on different components, a supervisor may decide that a walkthrough and the pre-job briefing need only be done once before the task is performed the first time. If the same task is performed over several weeks or days, system configurations may change between jobs or the personnel who are on-shift and assigned to perform the work may change. Without the walkthrough and briefing before the task is performed each time, personnel may commit errors because they are unaware of changed plant conditions or newly assigned personnel may not have a full understanding of the task requirements.

14.1.2 Oversight

In addition to directing work activities, first-line supervisors typically are responsible for overseeing performance of the work. Supervisory oversight entails monitoring the work activity to ensure it is performed in accordance with the work plan, procedures and management expectations.

Effective supervisors are technically qualified to independently detect and correct errors, with the same or a superior level of technical knowledge as the worker performing the task. Although this is not always possible, it is important for high risk, complex activities. The best supervisor for a particular task is not always a higher-level manager who may be less familiar with the details of the task. A worker who was recently promoted to the ranks of first-line supervisors may provide more effective oversight if he or she has recent technical knowledge of the activity and has mastered the necessary supervisory skills.

The supervisor may or may not participate in the work assignment, but if he or she participates, the ability to concurrently provide oversight may be momentarily lost or reduced. The key element of supervisory oversight is that it provides a "second pair of eyes" not involved in the work activity that can detect errors and act promptly to correct them.

14.1.3 Leadership

Leadership involves motivating personnel, building trust, maintaining accountability and empowering action. As the first level of line management, the supervisor plays a key role in establishing and maintaining the work group's norms, values and safety culture. In addition, the supervisor's leadership style will affect the team's performance.

Supervisors translate and apply general organizational goals and management expectations to the specific activities of the work group. This process occurs both overtly, with explicit communications about goals and expectations, as well as indirectly. Goals and expectations, for example, may be communicated indirectly by the example the supervisor sets with his or her work behavior, such as the extent to which he or she takes short-cuts when performing tasks. Expectations may also be indirectly communicated through tacit behaviors, such as a failure to correct worker actions that achieve production goals while circumventing safe work practices. Supervisors also communicate goals and enforce management expectations through the worker behaviors that they reward with recommendations for promotions, merit raises and/or bonuses, desirable work assignments, training opportunities and overtime allocations, and even with such

subtle rewards as individual attention for some subordinates. Supervisors may overtly or covertly discourage a questioning attitude among workers, for example, by not taking time to fully answer questions during meetings, or, at an extreme, by ridiculing staff members who raise questions and concerns.

In addition to communicating organizational goals and management expectations, the supervisor's leadership style affects team performance. The research literature shows that leadership styles generally range from participative, with a focus on establishing and maintaining good interpersonal relations, to authoritarian and task-focused. The most effective leadership style in a given work situation depends upon the characteristics of the work situation and of the team members.

A participative leadership style is effective when team members are experienced, the task is moderately structured, and time pressure is absent. For example, a brainstorming session for the development of an improved work control process will benefit from participative leadership where the formal operational lines of authority are suppressed and the participants interact as equals.

A more authoritarian leadership style is effective when team members are new to the task, the work is either unstructured or is highly structured, or the work must be completed under time pressure. In a nuclear power plant control room, for example, authoritarian leadership would be critical during emergency operations if a crew were faced with new and unanticipated circumstances and had to respond rapidly.

An effective supervisor adapts his or her personal style to the requirements of the task at hand. This flexibility does not come naturally to many people and supervisory training may be required to modify an individual's leadership style. For example, an experienced first-line supervisor with a strong authoritarian personality that served him or her well in the maintenance department may have to adopt a more participative, coaching style of leadership when he or she is promoted to a management position. Supervisors who are able to change leadership style to adapt to the demands of the situation lead consistently high performing teams.

Mismatches between the leadership style applied in a given work situation and the task demands may cause or contribute to errors in several ways. For example, team members may attempt to debate a verbal instruction from a supervisor who has been consistently participative at a time when it is necessary to implement an order promptly. A consistently authoritarian leadership style may discourage team members from offering ideas that could solve a problem or from raising valid concerns when their input could prevent an unwanted outcome.

14.2 DIRECT CAUSES OF SUPERVISION ERRORS

A direct cause of a supervision error describes the characteristics of supervision that either caused the human error or failed to prevent a human error when prevention was possible. Supervision may play a role in errors through weaknesses in direction, oversight or leadership. Specific examples of direct supervisory causes for errors are presented below.

14.2.1 Direction

Task goals not defined – Task performance failed because personnel were not informed of the goals of the task by supervision prior to starting the job. As a result, for example, the job may be performed on the wrong system or equipment or performed incorrectly.

Task methods not defined – Task performance failed because personnel did not receive necessary guidance from supervision regarding management expectations for how the task was to be performed. The supervisor may not have provided a pre-job briefing or ensured that the work package was complete and included the necessary drawings or procedures.

Unusual or hazardous conditions not identified – Task performance failed because unusual or hazardous conditions at the worksite were unknown to the workers. Supervision may not have walked down the job in advance with the workers to identify any unusual equipment or environmental conditions that could require special tools or equipment or a change to the planned work methods. As a result, errors may occur when the workers encounter unexpected conditions.

Prerequisites not met – Task performance failed because supervision did not ensure that all of the prerequisite conditions were met prior to allowing the job to start. As a result, for example, necessary tools and equipment were not available to perform the work timely, or the equipment was not tagged out and ready for the work to be performed.

Authorization not obtained – Task performance failed because supervision did not ensure that authorization was received before the job was started, or, if the work was delayed, that the authorization continued to be valid. As a result, for example, the job may have conflicted with other work being performed or safety systems may have been taken out of service without the control room's knowledge.

Resources not provided – Task performance failed because supervision did not ensure that workers had the resources required to perform the task. These resources could include information, procedures, guidance or assistance in solving problems that arise.

Qualifications not assured – Task performance failed because supervision assigned workers to tasks for which they were not qualified. As a result, errors were committed and the task was performed incorrectly or incompletely.

Decisions/guidance incorrect – Task performance failed because supervision was not technically competent to direct the work activity and so made decisions or provided guidance that was technically incorrect.

14.2.2 Oversight

No oversight – Task performance failed because supervision was not present during the performance of important tasks or critical portions of a job, with the result that errors were not detected, corrected or prevented.

Oversight unqualified – Task performance failed because supervisory oversight was present, but was not sufficiently familiar with the work to detect and correct or prevent errors.

Oversight distracted – Task performance failed because supervision was involved in performing the job or attending to other matters.

14.2.3 Leadership

Wrong goals – Task performance failed because supervision communicated, directly or indirectly, an emphasis on production or cost goals over safety. As a result, for example, workers may have skipped steps or used alternate methods to those prescribed in the procedures or work package to complete the job quickly.

Questioning attitude discouraged – Task performance failed because supervision, directly or indirectly, discouraged workers from questioning work practices or instructions. As a result, workers may have taken actions that they believed were incorrect or possibly unsafe, or started work without fully understand the task.

Mismatched leadership style – Task performance failed because there was a mismatch between the supervisor's leadership style and the task demands. As a result, teamwork or morale were adversely affected and led to errors.

14.3 PROGRAMMATIC CAUSES OF SUPERVISION ERRORS

Programmatic causes for supervision errors are typically found in the licensee's human resources and training programs. Licensee human resources programs are responsible for ensuring that personnel selected and promoted to supervisory positions are qualified to supervise. Selection and promotion processes screen for technical qualifications and often also assess candidates' decision-making capabilities, leadership skills and other attributes that predict success in the position. Technical training and training in supervisory skills assure that supervisors can fulfill their functions. Other programs may also be implicated.

14.4 ADDITIONAL RESOURCES ON SUPERVISION

- U.S. Nuclear Regulatory Commission (2000). *Qualification and training of personnel for nuclear power* plants (Regulatory Guide 1.8, Rev. 3). Washington, DC: U.S. Nuclear Regulatory Commission

- U.S. Nuclear Regulatory Commission (2000). *Medical misadministrations caused by human errors involving gamma stereotactic radiosurgery (gamma knife)* (Information Notice 2000-22). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1981). *Standard review plan*, (NUREG-0800), Chapter 13, Conduct of operations, Sections 13.1.1-13.1.3. Washington, DC: U.S. Nuclear Regulatory Commission.

15 HUMAN-SYSTEM INTERFACE

15.1 THE HUMAN-SYSTEM INTERFACE AND HUMAN PERFORMANCE

In NUREG-0711, " Human Factors Engineering Program review Model," the **human-system interface** (HSI) is defined as the technology through which personnel interact with plant systems to perform their functions and tasks. The major types of HSIs include alarms, information systems, and control systems. Each type of HSI is made up of hardware and software components that provide information displays, which are the means for user-system interaction, and controls for executing these interactions. Personnel use of HSIs is influenced directly by (1) the organization of HSIs into workstations (e.g., consoles and panels); (2) the arrangement of workstations and supporting equipment into facilities, such as a main control room, remote shutdown station, local control station, technical support center, and emergency operations facility; and (3) the environmental conditions in which the HSIs are used, including temperature, humidity, ventilation, illumination, and noise.

Use of the HSI is also affected indirectly by other aspects of plant design and operation, including training (Section 9), supervision (Section 13), staffing (Section 14), and communications (Section 17), which are addressed in other modules. Plant procedures also are considered part of the HSI, as defined by NUREG-0711. However, in the HPEP, a separate module (Section 11) addresses the information content and design of procedures, while this section addresses the user-system interface considerations of computer-based procedure systems as part of the HSI.

In determining the causes of a human performance problem, the licensee may identify specific characteristics of the HSI that led to error. Methods for evaluating HSI characteristics and detailed review guidelines are available in NUREG-0700, "Human System Interface Design Review Guideline." The major topics to consider in evaluating the HSI and determining whether HSI characteristics had an impact on an error are summarized below.

15.1.1 HSI Design Process

Licensees are responsible for the original design of an HSI and any subsequent upgrades and modifications, whether the licensee, a contractor or vendor did the work. A central concern of the design process is ensuring that the HSI will support correct human performance.

There are three important goals to be achieved in the design and implementation of an HSI. These are:

- **Design for operability** refers to designing the HSI to be consistent with the abilities and limitations of the personnel who will be operating it. Weaknesses in the design processes can result in an HSI that is not well suited to the tasks that personnel must perform to ensure plant safety, resulting in increased workload, decreased performance by personnel, and an increased likelihood of errors.

- **Design for maintainability** refers to designing the HSI and associated plant equipment to ensure that personnel are able to perform necessary maintenance activities efficiently. Weaknesses in the design process can result in systems that impose excessive demands on personnel for maintenance and, therefore, are prone to maintenance errors or problems with reliability and availability.

- **Design for implementation** refers to the way that changes, such as upgrades to the HSI, are planned and put into use. A new HSI component may require the user to perform functions and tasks in new ways. Skills that the user developed for managing workload when using the former design, such as ways for scanning information or executing control actions, may no longer be compatible with the new design. The new HSIs must also be compatible with the remaining HSIs so that operators can use them together with limited possibilities for human error. Also, HSI modifications may not be installed or put into service all at one time, causing the user to adapt to temporary configurations that are different from both the original and final configurations. Weaknesses in HSI implementation can increase operator workload and the likelihood of errors.

15.1.2 HSI Characteristics

The characteristics of HSIs that have been found to affect human performance are discussed below. In this section, each HSI characteristic is introduced and defined, and the potential impacts of HSI weaknesses on performance are briefly discussed.

15.1.2.1 Information Display

Information **display** refers to the way that information is presented to personnel. Both the **display devices** and the displays contained in the devices are addressed by this topic. Display device considerations include their location in the work environment and factors that affect legibility, such as brightness and flicker. Display considerations include how information is organized and presented within the display device. A **display page** is a set of information that is presented at one time by a display device. **Display formats** refer to standard groupings of information within pages, including text, tables, graphs, and mimics. **Display elements** refer to the items that make-up the formats, such as characters, numbers, symbols, and icons. Other considerations include whether needed information is present and available, and the quality (i.e., reliability) of the plant data provided to the user. Weaknesses in information display can affect the ability of personnel to promptly and correctly detect, read, and understand information needed to perform their tasks.

15.1.2.2 User-System Interaction

User-system interaction is the set of methods provided in a computer system through which personnel and the computer communicate with each other. The following topics are included. User input formats refers to the type of dialogue between the user and the computer. **Cursors** are pointers that indicate the position of the user's operation on a display screen. **System response** refers to the manner in which the computer system behaves after receiving inputs from the user. **Managing displays** refers to the actions performed by a user to control the way that individual displays are presented on a device. **Managing information** refers to capabilities that

allow the user to create, change, store, and retrieve documents via the computer. **Managing errors** refers to features that support the prevention, detection, and correction of errors. **Help** refers to features that provide guidance to the user (e.g., describes how the user interface works). **System security** includes features that restrict personnel access to aspects of the computer system to prevent accidental or deliberate damage. Weaknesses in user-system interaction can increase the amount of effort for the user to find and arrange needed information. These weaknesses can also inhibit the user's ability to prevent, detect, correct, and recover from errors.

15.1.2.3 Controls

Controls are devices that personnel use to interact with the HSI and the plant. They may be conventional, hardwired control devices or computer-based input devices. Weaknesses in the design of control devices, whether conventional or computer-based, can interfere with the ability of users to perform control or input actions promptly and without errors.

15.1.2.4 Alarm Systems

Alarm systems are automated systems consisting of processing and display hardware and software, which analyze signals from plant sensors and alert the operator via visual or auditory displays (i.e., when the monitored parameters deviate from specified limits). Important characteristics include processing functions; information display; user-system interaction; controls; reliability; test and maintenance capabilities; failure indications; alarm response procedures; control-display coordination; and its integration with the rest of the HSI. Alarm system weaknesses can increase personnel workload associated with finding and assessing plant information and decrease operator awareness of plant status.

15.1.2.5 Soft Control Systems

These are computer-based systems that provide operators with control interfaces that are mediated by software rather than direct physical connects, as in hard-wired knobs and buttons. **Soft controls** can be used to control plant equipment, such as a pump, or the HSI, such as in selecting a display. Important characteristics of soft control systems include the information display, user-system interaction, controls, and integration with the rest of the HSI. Weaknesses in the design of soft control systems can increase the likelihood of human performance problems, such as unintentional actuation, incorrect inputs (i.e., wrong control, wrong input value), and delayed completion of control actions.

15.1.2.6 Computer-Based Procedure Systems

These systems present plant procedures in computer-based rather than paper-based formats. **Computer-based procedures** (CBP) systems can present procedures steps and plant status information in ways that better support decision-making. They can also include capabilities for managing multiple procedures and procedure steps. Important characteristics include processing capabilities (automation for procedure functions), information display, user-system interaction, controls, and integration with the rest of the HSI. Weaknesses in the design of CBP systems can increase workload associated with assessing plant status and selecting appropriate responses and decrease operator awareness of plant status.

15.1.2.7 Computerized Operator Support Systems

These systems use computer technology to support operators or maintenance personnel in situation assessment and response planning. They can monitor status and provide recommendations or warnings. Example applications include: fault detection and diagnosis, safety function monitoring, plant performance monitoring, core monitoring, maintenance advising, and operator support for plant control. Important characteristics include processing capabilities, information display, user-system interaction, controls, and integration with the rest of the HSI. Weaknesses in the design of **computerized operator support systems** can increase workload associated with assessing plant status and selecting appropriate responses and decrease operator awareness of plant status.

15.1.2.8 Workstations

Control, display, and alarm devices of the HSI are often organized into **workstations** where crew functions and tasks are performed. Examples include sit-stand workstations, stand-up consoles, sit-down consoles, vertical panels, and desks. Workstation characteristics affect reach, vision, comfort, the ability to gather and compare information across display devices, and the ability to use control and display devices in a coordinated fashion. Weaknesses in workstation design can interfere with the ability of personnel to detect important information or accurately perform control and computer input actions.

15.1.2.9 Control Room

A control room is a facility in which controls and displays of the HSI are centralized (e.g., the main control room and the technical support center). Two important aspects of a control room are its configuration (i.e., its arrangement of workstations and other equipment) and its environment (i.e., the adequacy of lighting, temperature, humidity, and ventilation for normal and emergency conditions). Weaknesses in control room layout may interfere with the ability of personnel to detect and monitor information and interact with each other. Weaknesses in lighting may affect the ability of personnel to accurately read displays, procedures, and other information sources. Weaknesses in lighting, temperature, humidity, or ventilation may also affect personnel alertness, comfort, and health.

15.1.2.10 Local Control Stations

Local control stations are places outside of the main control room, where operators interact with the plant. They may include multifunction workstations and panels, as well as individual interfaces, such as controls (e.g., valves, switches, and breakers) and displays (e.g., meters and VDUs). When implemented in environments that are not as carefully controlled as the main control room, local control stations may have special considerations such as high levels of background noise and severe environmental conditions. Weaknesses in control station layout may interfere with the ability of personnel to detect and monitor information, perform control actions, and interact with other personnel. Weaknesses in lighting may affect the ability of personnel to accurately read displays, procedures, and other information sources. Weaknesses in temperature, humidity, or ventilation may affect personnel performance, comfort, health, and safety.

15.1.2.11 Maintainability Features

All plant equipment, including the HSI, must be periodically maintained. The design of the maintenance interfaces of plant equipment and the tools used in maintenance tasks can affect personnel performance for these tasks. **Maintainability** refers to the design of features and capabilities that support personnel in detecting equipment failures and performing necessary preventive, routine, and corrective maintenance. This includes the layout of components that must be maintained, labels and markers, controls for adjusting equipment, **test points**, service points, and test equipment (e.g., the user interfaces and capabilities of diagnostic devices). An area that is posing increasing human performance challenges in NPPs is the maintenance of digital systems, due to the complexity of these systems and their susceptibility to incorrect actions. Some maintainability considerations for digital systems include the design of: instrument cabinets and racks, equipment packaging within these enclosures, and fuses and circuit breakers. Weaknesses in the design of maintenance interfaces and tools can increase the likelihood of maintenance errors and the amount of time needed to complete maintenance tasks. This may increase the occurrence of plant transients or decrease the availability of plant equipment needed to ensure plant safety.

15.2 DIRECT CAUSES OF HSI-RELATED ERRORS

A direct cause of an HSI-related error describes characteristics of the HSI that caused task performance to fail. There are a number of ways in which the HSI may cause, contribute to or fail to prevent an error. These include:

15.2.1 Information Display

No display or information not available – Needed information was not displayed or the information that a display was intended to provide was not available. As a result, the user did not have access to the information needed to perform the task.

Display formats, elements or pages unsuitable – The display was formatted (e.g., text, tables, graphs, mimics, speech output) or display elements (e.g., characters, numbers, symbols, icons) were presented in a manner that made them difficult to read, understand or use. As a result, personnel did not or could not use the information displayed when performing the task.

Data quality and update rate inadequate – The display did not provide useful indications of the quality of the data that was provided or the update rate of the data was too slow to be useful. As a result, users were unable to depend on and use the information displayed to guide task performance.

Display equipment inadequate – The equipment used to display information (e.g., VDUs, printers, plotters, meters, light indicators, numerical readouts, and audio devices) did not work or was unsuitable for performing the task. As a result, users did not have access to necessary information.

15.2.2 User-System Interaction

User input formats unsuitable – The format provided by which personnel interacted with the system (e.g., command language, menus, function keys, response entry forms, direct manipulation, query language) was unsuitable for the task. As a result, user inputs were delayed or input errors occurred.

Cursor inadequate – The type of cursor provided was too small or otherwise difficult to see on the screen, or was difficult to manipulate and understand. As a result, task performance was delayed or input errors were committed.

System response inadequate – The HSI did not provide adequate feedback to the user or response times were too slow. For example, prompts regarding the expected input were not provided, no feedback was given when the user entered an input, or the time between an input and the system's response to it was too slow to maintain control.

Display management difficult – Methods for managing displays (e.g., selection, navigation, freeze/update, scroll, page, pan and zoom) were not provided or difficult to use. As a result, personnel could not access needed information or could not access it timely.

Information management inadequate – Means to create, change, store and retrieve documents were not provided or were difficult to use. As a result, needed information was lost.

Errors difficult to detect and correct – The HSI did not provide means to catch input errors or provide easy means to correct them. As a result, errors were made and neither detected nor corrected.

Help function missing or inadequate – Assistance in using the system was not provided or was difficult to access. As a result, personnel could not use the system to perform their tasks.

System not secure – Security features were missing. As a result, personnel caused accidental or deliberate damage.

15.2.3 Controls and Soft Control Systems

Controls not available – The HSI did not provide all the controls necessary to perform the task. For example, controls were not available for selecting plant variables to view or to act upon or means were not provided for monitoring feedback.

Controls not integrated – Control actions or control devices were inconsistent or incompatible with other aspects of the HSI. As a result, personnel took incorrect actions when operating the controls.

Computer-based input devices inadequate – The input devices (e.g., keyboards, trackballs, joysticks, mice, touch screens, light pens, graphic tables and speech input devices) did not work or were unsuitable for the task. As a result, user inputs were delayed or errors committed.

Conventional control devices inadequate – The hardwired control devices (e.g., push buttons, rotary controls, thumbwheels and switches) did not work or were unsuitable for the task. As a result, control actions were delayed or errors occurred.

No backups – Alternate means for taking control actions on critical tasks were not provided should the controls fail. For example, no hardwired backups for soft controls were available, if the soft controls failed.

15.2.4 Alarm Systems

Alarm functions missing – Alarms to alert, inform, guide or assist personnel were not provided. As a result, personnel did not detect important changes in system state or did not have access to needed information to perform their tasks.

Alarm display inadequate – Necessary information was not presented in either an auditory or visual format that was effective in drawing attention and conveying detailed information. As a result, personnel had difficulty detecting and diagnosing system states, leading to errors.

User-alarm interactions inadequate – Silence, acknowledge, reset and test controls were not provided or did not function correctly. As a result, the user was unable to interact effectively with the alarm.

Failure indications missing – The alarm system did not indicate when it was not functioning or it was difficult to determine whether the alarm was operable. As a result, personnel were not aware that alarms were not operable and so did not detect important changes in plant state.

Alarm response guidance missing – Detailed information about alarm conditions and appropriate actions to take in response to alarms (e.g., alarm response procedures) was not available to personnel. As a result, response was delayed or incorrect.

Alarms not integrated – Display and control arrangements for the alarm system were difficult to use or were inconsistent or incompatible with the rest of the HSI. As a result, incorrect actions were taking when interacting with the alarms or use of the alarm system interfered with actions required by other aspects of the HSI.

15.2.5 Computer-based Procedures and Operator Support Systems

Information missing or inadequate – The computer-based procedures or computerized operator support systems did not provide the information users required or it was not

presented in a format that supported performance. For example, the level of detail was insufficient to assist personnel in decision-making.

User-system interactions inadequate – The computer-based procedures or computerized operator support system displays and controls were difficult to understand or manipulate. As a result, personnel responses were delayed or incorrect.

Not integrated – The computer-based procedures or computerized operator support systems were inconsistent or incompatible with the rest of the HSI. For example, control and display devices operated differently from those used for other systems leading to errors.

No backups – No alternate hard-copy procedures or hardwired systems were provided in case of computer-based procedures or computerized operator support system failures. As a result, if the systems failed, personnel had no procedural guidance for performing their tasks.

15.2.6 Workstations

Configuration inadequate – The workstation design did not support user reach, vision or comfort. As a result, for example, personnel became fatigued, could not see important information or were delayed in taking control actions.

Layout inadequate – The layout of controls and displays on the workstation did not support control actions. As a result, personnel became fatigued or made errors when using the controls.

Labeling and demarcation inadequate – Labels and markings did not assist users in finding and identifying controls, displays and other equipment. As a result, for example, personnel used the wrong controls for the intended action or read the wrong display.

15.2.7 Control Room

Space and layout inadequate – Sufficient space was not available or equipment was laid out in ways that it was difficult for personnel to view or access information, communicate or walk around. Or, there was inadequate space available to store needed procedures, other documents, spare parts, expendables, tools, protective equipment and personal items. As a result, for example, procedures could not be laid out so that placekeeping was difficult or needed items were lost and prevented task completion.

Supervisor inaccessible – Access to the shift supervisor's office via walking or communication links was difficult. As a result, the supervisor was unavailable when needed or was unable to maintain awareness of control room activities.

Multi-units not distinguishable – Features to distinguish between controls and displays for different units, or mirror-image control rooms, caused personnel to incorrectly monitor plant parameters or take control actions on the wrong unit.

15.2.8 Local Control Stations

No display or information not available – Needed information was not displayed or the information that a display was intended to provide was not available. As a result, the user did not have access to the information needed to perform the task.

No controls or controls not available - The controls necessary to perform the task were either missing or not working at the local control station. As a result, necessary control actions could not be performed.

Layout inadequate – The layout of controls and displays at the local control station did not support control actions. As a result, personnel could not accurately determine system status and made incorrect operational decisions.

Labeling and demarcation inadequate – Labels and markings did not assist users in finding and identifying controls, displays and other equipment. As a result, for example, personnel used the wrong controls for the intended action or read the wrong display.

15.2.9 Maintainability

Equipment inaccessible – The arrangement of components and access to them for inspection, testing, replacement and repair was inadequate. As a result, maintenance activities were delayed or errors were committed.

Labeling and demarcation inadequate – Labels or markings did not support proper identification of equipment and components. As a result, task performance was delayed while personnel attempted to identify the correct piping.

Adjustment controls missing or inadequate – Control devices for performing adjustments on equipment were not provided or were inconvenient to use. As a result, setpoints could not be accurately maintained.

Test and service points missing or inadequate – Test and service points were not provided or were inconvenient to access and use. As a result, personnel skipped a surveillance rather than attempt to access a test point.

Test equipment inadequate – Equipment needed for testing was not available, was difficult to use, was miscalibrated or was otherwise not properly configured for the maintenance task. As a result, the maintenance task was not completed or equipment operability following maintenance could not be verified.

15.3 PROGRAMMATIC CAUSES FOR HSI-RELATED ERRORS

Licensees may have many programs, processes, and practices to ensure that human factors engineering considerations are properly addressed in the design and installation of the HSI and other plant equipment, and that human performance considerations continue to be met in on-going operations after installation. There are three primary programs or processes that may set the stage for HSI weaknesses that cause errors. These are the HSI design and implementation process, and maintenance and housekeeping activities. If the display system is not fully operational, contains outdated information, or has labels that are either illegible due to accumulated dirt or missing, the licensee should consider programmatic causes related to its repair, maintenance, and general housekeeping.

> <u>HSI Design</u> – The HSI design and implementation process assures that original HSI designs and upgrades fully meet the needs of operations and maintenance personnel and that problems are avoided when the new design is put into service. If design and implementation processes are deficient, weaknesses will exist in the HSI. For example, a poorly designed display system or controls that are difficult to use may result from an inadequate design process.

> <u>Maintenance</u> – A licensee may have a variety of programs for ensuring that the HSI and plant equipment are in working order and available for use. These include preventative, routine, and corrective maintenance programs for both hardware and software components. An important concern for software maintenance is ensuring that the computer system is updated with the most current and correct set of instructions and data. Another maintenance concern is the replacement of missing or degraded labels throughout the plant. Weaknesses in these programs can result in the HSI being inadequately or incorrectly serviced, resulting in problems with reliability and availability.

> <u>Housekeeping</u> – Housekeeping includes activities performed to maintain a clean and orderly work environment. Examples include cleaning labels and displays so they can be easily read, cleaning input devices so they can be used properly, removing trash and used materials to eliminate unnecessary clutter, and storing documents so they can be readily accessed when needed. Housekeeping practices refers to the way these tasks are performed on an ongoing basis to maintain a productive work environment. Weaknesses in housekeeping practices can increase operator response time and the likelihood of errors.

15.4 ADDITIONAL RESOURCES ON THE HSI

- U.S. Nuclear Regulatory Commission (1996). *Standard review plan for the review of safety analysis reports for nuclear power plants* (NUREG-0800). Washington, D.C.: U.S. Nuclear Regulatory Commission.

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16 TASK ENVIRONMENT

16.1 EFFECTS OF ENVIRONMENTAL FACTORS ON HUMAN PERFORMANCE

The **task environment** refers to the physical conditions in which work is performed. Environmental conditions that can affect performance include excessive vibration and noise, temperature extremes and insufficient lighting. These adverse environmental conditions can stress personnel, interfere with performance and increase the likelihood that they will commit errors while performing a task. Work conditions that require protective gear, such as high radiation or some confined space environments, or that require unusual physical postures, also can interfere with task performance, as may poor housekeeping.

16.1.1 Vibration

There are two types of vibration that may cause errors. The first is **whole-body vibration**, in which vibration is transferred to the worker from standing or sitting on a vibrating surface. The second is **object vibration**, in which a stationary worker interacts with a vibrating object in some fashion. The effects of vibration depend upon its frequency and acceleration. **Frequency** is the number of oscillations (cycles) that occur in one second. **Acceleration** is the force, or intensity, of the vibration.

Whole-body vibration affects personnel comfort levels. As discomfort increases, errors may occur. Personnel are most uncomfortable when the frequency of the vibration approaches the resonance point of the human body (5 Hz) and can tolerate only short exposures. Discomfort also increases as acceleration increases. Discomfort may induce errors by causing personnel to rush through their work or by distracting them.

Whole-body vibration also affects the ability to control fine hand and arm movements. Vibration will induce errors in tasks that require accurate hand and arm movement, such as writing, placing and tightening screws, or attaching jumpers.

Vibration also blurs vision. Errors may occur from vibration on tasks that require accurate vision, such as reading instruments, procedures or drawings.

Object vibration may also adversely affect performance. For example, errors may occur when making fine adjustments or in reading instruments, if equipment is vibrating.

16.1.2 Noise

Noise is unwanted sound. Noise can cause errors in several ways. It may disrupt communications, affect the ability to perform tasks and annoy personnel.

The effects of noise on communications are complex. Even relatively low levels of noise can mask speech, but only under some circumstances. For example, speakers naturally raise their voices when there is background noise and may be able to overcome some of its effects on

communication. Being able to see the speaker's face or using standardized phrases also improves communication in a noisy environment. The type of background noise also affects communication. It is easier to communicate over noise that is steady and uniform than noise that includes sharp tonal peaks, such as background speech.

Noise has been shown to affect decision-making, memory, vigilance, attention and motor skills. Whether noise will cause errors depends upon (1) the degree of familiarity with the noise, (2) the complexity of the task the worker is performing and (3) the frequency and intensity of the noise, measured in decibels.

Familiar noises are usually continuous, such as the sound of freeway traffic or the hum of a motor. Even high levels of familiar noise typically do not impair performance on simple tasks and will cause only minor effects on complex tasks, such as reading or decision-making.

Unfamiliar noise is more disruptive. Unfamiliar noise includes speech, alarms and some kinds of music. Loud and unfamiliar noise may cause only minor performance effects on simple tasks, but will disrupt performance of complex tasks. Multiple alarms sounding simultaneously in a control room, for example, could interfere with performance of complex tasks.

Unfamiliar, loud noise is also annoying. Annoyance may cause workers to rush through their tasks or disrupt teamwork. Unexpected and unfamiliar loud noise, such as sonic booms from line breaks, may startle personnel.

16.1.3 Heat

Heat exposure is a common problem in many areas of a plant, such as the turbine building when the plant is operating. The extent to which workers will be affected by heat depends on many factors. These include physical characteristics, such as age, weight, acclimation to heat, physical fitness and dehydration. Other factors that determine the effects of heat on performance include airflow, humidity, clothing and level of physical activity.

As **whole-body temperature** (a measure of internal body temperature that is estimated externally by wet-bulb globe temperature - WBGT) increases, first the workers' comfort levels are affected, then task performance is affected, followed by the onset of heat stress. Performance of perceptual/motor tasks, such as tracking, monitoring, and manipulating objects, is affected even at relatively low temperatures (69°F WBGT). Performance on perceptual/motor tasks degrades over the first two hours of exposure, and then levels off. Performance of mental tasks, such as arithmetic computations, logical reasoning, and recalling information from memory, begins to degrade sharply after about 30 minutes of exposure to temperatures above 90°F WBGT, but then levels off. When workers begin to experience heat stress, they may become confused and disoriented, in addition to experiencing physical symptoms, and are very likely to commit errors if they attempt to continue working.

16.1.4 Cold

Exposure to cold affects the performance of manual tasks. Decreases in the ability to control hand movements begin at an air temperature of approximately 54° F. The fingers may become

numb to pain at this temperature and touch sensitivity is reduced. Performance of gross manual tasks, such as those involving the arms and legs is also degraded at 54° F. The speed at which manual tasks can be performed is affected by the rate of cooling. Slow temperature drops have a greater negative impact on manual dexterity than rapid temperature decreases, during the initial exposure period.

Hypothermia occurs when a worker can no longer maintain an adequate deep-body temperature. In the early stages, individuals experience lethargy, clumsiness, confusion and irritability. As the hypothermia deepens, hallucinations or arrested breathing will occur.

The effects of cold temperatures on performance are affected by clothing, whether exposed skin and clothing are wet or dry, air movement (wind chill) and the length of exposure. Performance impairments may be experienced at higher air temperatures than those discussed above if workers are not dressed warmly, their skin or clothing is wet, or they are exposed to air movement or to cold temperatures for extended periods of time.

16.1.5 Lighting

Adequate lighting is required for accurate performance of nearly every task in a nuclear power plant. Visibility depends upon several factors:

- The intensity of the light radiated by a light source, measured by **candle power**
- The amount of light striking an object from a light source, known as its **illuminance**
- The perceived brightness of an object, known as its **luminance**, which depends upon the object's reflectance
- The difference between an object's luminance compared to the luminance of the object's background, or **contrast**
- The object's size
- The individual worker's age and visual acuity.

Visibility is also affected by changes in light levels as the eyes adapt. Individuals have particular difficulty seeing while their eyes are adapting to a different level of illuminance, such as entering a darkened room from full sunlight.

The ability to accurately perceive colors (**color discrimination**) is also affected by lighting. Color discrimination may be reduced by the characteristics of the light source. For example, high-pressure sodium discharge lamps reduce the ability to discriminate colors, while artificial daylight fluorescent lamps maintain it. Very low lighting levels also adversely affect color discrimination.

Glare and flicker will also reduce visual performance. **Glare** occurs when the luminance level (the amount of light reflected from an object) is annoying. It may reduce contrast, interfere with reading and inspection tasks and cause visual fatigue. **Flicker** causes discomfort and eye fatigue when reading.

16.1.6 Other Adverse Task Conditions

Other adverse environmental conditions may also affect task performance. In general, any physical conditions that require the use of PPE or devices complicate task performance, may be stressful and so may increase the likelihood of errors (see Section 12, Tools and Equipment.) For example, working in confined or elevated spaces may encourage personnel to hurry through their tasks and so commit errors. Working in high radiation environments may require that task performance be repeatedly interrupted to minimize exposures. Poor housekeeping may increase the likelihood of trips and falls, or obscure displays and controls. Working on ladders or platforms, or in cramped working conditions that require unusual physical postures may cause discomfort, can be distracting and may increase the likelihood of errors.

16.1.7 Combinations of Conditions

Most of the research that has examined the effects of environmental factors on human performance has been done in the laboratory or in other highly controlled settings. In most industrial settings, environmental factors are not as rigidly controlled and often fluctuate. Further, in industry, adverse environmental conditions often occur together, such as high noise levels and excessive heat when high-energy equipment is operating. Large fluctuations in conditions and combinations of conditions have not been as thoroughly studied. There is some evidence to suggest, however, that performance degradations are more severe under fluctuating and/or combined conditions.

16.2 DIRECT CAUSES OF TASK ENVIRONMENT-RELATED ERRORS

A direct cause of a task environment error describes the physical conditions that caused task performance to fail. There are a number of ways in which characteristics of the task environment may impair performance. These include:

> Vibration - Task performance failed because high levels of whole-body or object vibration made displays, instruments or documents difficult to read or caused discomfort. For example, vibration prevented a worker from accurately reading a piping and instrumentation diagram.
>
> Noise - Task performance failed because high noise levels interfered with communications, caused discomfort, or impaired mental or physical performance.
>
> Heat - Task performance failed because excessive exposure to heat caused discomfort or impaired mental or physical performance. Or, the need for frequent work breaks delayed task completion or increased the communication burden on personnel due to rotations.
>
> Cold - Task performance failed because excessive exposure to cold caused discomfort or impaired motor performance. For example, workers dropped tools or were unable to manipulate controls.

Lighting - Task performance failed because lighting was excessive, insufficient, the wrong type for discriminating color, or produced annoyance from glare or flicker. For example, a computer screen was difficult to read due to glare.

Poor housekeeping - Task performance failed because displays or controls were obscured by trash or equipment that should have been stored. Workers tripped over or were required to walk out of their way to avoid tools or equipment that should have been removed.

Workspace - Task performance failed because the worker had insufficient space to perform the task or had to assume uncomfortable positions.

High radiation – Task performance failed because workers were hurried or their activities were repeatedly interrupted to avoid excessive exposures.

Combinations of factors - Task performance failed because a combination of environmental factors impaired performance. For example, a job in the turbine building involved exposure to heat, noise and low lighting, none of which individually exceeded levels at which performance is affected, but the combination of conditions distracted the workers and caused errors.

16.3 PROGRAMMATIC CAUSES OF TASK ENVIRONMENT ERRORS

Programmatic causes of task environment errors are typically found in the licensee's processes for designing human-system interfaces or in managing maintenance activities. Other programs may also be implicated. Common programmatic causes of task environment errors include:

Industrial Hygiene and Radiation Protection – These programs are responsible for ensuring that task environments have been evaluated to identify hazards and that needed controls are implemented to minimize exposures. Weaknesses in these programs may result in personnel working in task environments that are conducive to errors.

Work Planning and Control - Weaknesses in the work planning and control system may allow work to be planned without consideration of adverse environmental conditions and performed without the necessary compensatory measures. For example, communication devices may not be provided in noisy environments to support task performance. For tasks that involve unusual physical positions or cramped workspace, additional time to complete the task may not be scheduled. Rest breaks for hot and cold environments may not be planned into the work, or additional temporary lighting may not be provided if the work site is not adequately lighted.

Procedures - Weaknesses in the licensee's procedure development process may result in the design of procedures that are inappropriate for the conditions in which they will be used. For example, procedures that may be used at night, outside and in the rain should

be laminated and the type size should be larger to ensure the procedure can be read. Procedures that will be used in vibration conditions may also require larger type size than procedures read in the stationary environment of the control room, for example.

Human Factors Engineering - Weaknesses in the human factors engineering program may result in the installation of new equipment or systems without consideration of task environment characteristics. For example, the impact of control room lighting on the visibility of digital displays or effects of vibration on the legibility of dials or gauges at local control stations should be considered before installation.

Operating Experience - Reviews of relevant operating experiences of the plant and other facilities with similar environmental conditions should be conducted to identify and analyze task environment problems and successful mitigation efforts. Personnel may have reported task environment conditions that interfered with performance that are recorded in the licensee's corrective action database, and corrective actions should have been implemented. Weaknesses in this program will result in repeated errors.

Labeling - Weaknesses in this program may result in tags and plaques that are illegible in the task environment, if low lighting levels or vibration are present.

16.4 ADDITIONAL RESOURCES ON TASK ENVIRONMENTS

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- U.S. Nuclear Regulatory Commission (1996). *Human-system interface design review guideline* (NUREG-0700, Rev. 1, Vol.s 1-3). Washington, DC: U.S. Nuclear Regulatory Commission.

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17 COMMUNICATIONS

17.1 COMMUNICATIONS IN ORGANIZATIONS

Communication is the exchange of information while preparing for or performing work. Verbal communication occurs face-to-face, by telephone, sound-powered phones or walkie-talkies, as well as over public address systems. Written communication occurs, for example, through policies, standards, work packages, training materials, and e-mail.

Communication involves two sets of behaviors: (1) creating and sending messages and (2) receiving and interpreting them. Communication always involves at least two individuals, the sender and the receiver, and occurs:

- Between individuals
- Within and among work groups
- In meetings
- In pre-job or pre-evolution briefings
- During shift turnover

Successful communication requires several steps. The sender first develops the intention to communicate either verbally or in writing. The sender then composes a message that presents the meaning as clearly as possible. The receiver must pay attention to the message and then interpret its meaning. If the communication is successful, the receiver interprets the message consistently with the sender's intended meaning.

The similarity of the meanings given to the message by the sender and receiver can be verified through feedback. An example of feedback verification in verbal communication is when the receiver "repeats back" the message and the sender either agrees with the receiver's repeat back or corrects it. Verification feedback serves an important error-checking function in the communication process. It also allows supervisory oversight of communications to catch errors before they have consequences.

A sender and receiver must both be active for communication to be effective. The sender and receiver share responsibility for ensuring successful communication. However, when licensees analyze the causes of events, errors in sending messages are more often identified than errors in receiving. The reasons for the difference are unclear. A licensee's investigation should consider sending and receiving errors and corrective actions should address both to be effective.

17.2 DIRECT CAUSES OF COMMUNICATIONS-RELATED ERRORS

A direct cause of a communication error describes the characteristics of the communication that caused it to fail. The direct cause of the error may be characteristics of how the message was sent or how it was received and interpreted. In some cases, a communication error will be compounded by failures in verification feedback or supervisory oversight.

There are a number of ways in which communication can fail. Research regarding communication errors in nuclear licensee facilities identified eleven direct causes of sending and five direct causes of errors in receiving:

17.2.1 Sending Errors

Content wrong - Communication failed because the information contained in the message was incorrect. For example, an operator in the control room refers to the wrong unit when giving instructions to an operator in the field.

Content inconsistent -Communication failed because, although the information in a message was correct, it was partially or completely inconsistent with other information available to the receiver. For example, a required surveillance test appears on a maintenance worker's schedule but his supervisor assigns him to another job and the surveillance is missed.

Content inappropriate for the job - Communication failed because the information in a message was irrelevant or inappropriate for the job at-hand. For example, a work order references a procedure that contains prerequisite conditions that cannot be met during at-power operations, but the maintenance worker attempts to perform the procedure anyway.

Content inappropriate for the receiver - Communication failed because the message was not tailored to the receiver's background, training or level of technical knowledge. For example, a non-licensed operator is instructed to perform a task on an unfamiliar system and cannot find it.

Standard terminology not used - Communication failed because complete identification information was not provided in the message. For example, a maintenance supervisor refers to a valve using a generic pronoun (e.g., "it"), rather than using the valve's proper name and number, and the maintenance crew works on the wrong valve.

Familiar terminology not used - Communication failed because unfamiliar terms were used in the message. For example, the formal name of a building, rather than the site-specific nickname, is used in a pre-job briefing and the crew is confused about which building is being discussed.

Message production inadequate - Communication failed because the message was not produced adequately. For example, a message is garbled when transmitted over the public address system or cannot be heard against background noise. A written communication contains typographical errors or copies are illegible.

Necessary information not sent - Communication failed because the information needed to perform a task was not provided to the worker. For example, a work order omits an instruction to obtain control room authorization before taking the component out of service.

Wrong place or person - Communication failed because necessary information did not reach the intended receiver. For example, a sender dials the wrong phone number or incorrectly addresses an e-mail message.

Wrong time - Communication failed because the message was sent too early or too late to be used by the receiver. For example, a maintenance worker finishes one job early and starts on the next before her supervisor has the opportunity to communicate that the job has been rescheduled.

Sending verification failure - Communication failed because the sender did not ensure that the receiver accepted and accurately interpreted the message. For example, a non-licensed operator calls the control room to report a leak and can tell that the control room operator is busy and distracted, so does not request that the control room operator repeat back the location and rate of the leak.

17.2.2 Receiving Errors

Information not sought - Communication failed because a receiver did not seek the information necessary to perform a task. For example, a work order references drawings needed to verify the location of a component, but the planner does not include them in the work package and maintenance technicians do not obtain and review them before starting work.

Information not found - Communication failed because the receiver, intentionally or unintentionally, did not find necessary information for performing a task. For example, an identification tag on a cable is hidden and the crew decides to perform the task without positively identifying the cable referenced in the work package, resulting in errors.

Information not used - Communication failed because the information necessary to perform a task was not used. For example, the need to wear electrical safety PPE is discussed at a pre-job briefing, but the instrumentation and control technician is in a hurry and performs the task without it.

Message misunderstood - Communication failed because the receiver misunderstood the message. For example, a control room supervisor and an operator discuss two related jobs, one of which requires establishing a fire watch. In the course of the discussion, the operator becomes confused about which job requires the fire watch and establishes the watch for the wrong job.

Receiving verification failure - Communication failed because the receiver did not take actions to test his or her understanding of the message received. For example, the control room operator in the fire watch example failed to repeat back or paraphrase the supervisor's message to check concurrence and to identify any gaps in the message or in his understanding of it.

17.3 PROGRAMMATIC CAUSES OF COMMUNICATIONS-RELATED ERRORS

Most work activities in organizations require coordination within and among work groups. Coordination requires effective verbal and written communication. Communication is necessary to define the work to be done and how to do it, so communication errors are frequently found to be causal factors in events. But, because so many work activities depend on effective communication, a wider variety of programmatic causes are associated with communication errors than with other types of human errors.

Programmatic causes that have been shown to cause or contribute to communication errors at nuclear licensee facilities are described below. Weaknesses in other programs at a licensee's site may also cause communication errors.

Information management - Flaws in programs for developing and managing technical documentation are a common source of communication errors. Omissions and technical inaccuracies in vendor manuals, engineering analyses, design basis or other reference documents may be translated into inaccuracies in procedures and work orders that are used to perform jobs. Failures to update drawings and procedures when new hardware is installed or existing hardware is modified can result in communication errors.

Work Planning and Control - Planning and scheduling maintenance activities is a complex task. Weaknesses in work planning and control programs may result in both written and verbal communication errors associated with, for example, inadequate work orders, inadequate pre-job briefings, or communication failures during job performance.

Shift Staffing - Insufficient staffing can increase the workload for those performing a job, and so interfere with required communications. Increased workload during plant outages and the increased numbers of workers on-site, or increased workload during off-normal events, can tax the supervisory abilities of those responsible for coordinating the work, resulting in incomplete or too few communications. Too many staff involved in performing a job can increase the communication burden on all involved and result in communication failures.

Training - Effective communication requires some degree of shared understanding of the work to be performed. Inadequate job knowledge, resulting from deficient training or qualifications, can lead to both sending and receiving errors. Effective communication also depends upon an understanding of the information needs of those involved in performing a job. Communication across organizational boundaries (e.g., between individuals in different departments, in different job roles, or on different shifts) can cause problems because senders and receivers may not understand one another's terminology or the contexts and constraints of the other's job.

Procurement and Maintenance – Some communications occur across physical distances through communication devices. Procurement and maintenance programs ensure that communication devices are suitable for their intended uses and are working properly. Communication errors can arise here, for example, when there is too much background

noise for a receiver to hear a public address announcement or what is being said on the radio or over the telephone. An insufficient number of radio frequencies to support communication needs may also cause or contribute to communication errors.

Supervision - Some communication failures occur as a result of human errors in job performance. These errors can often be caught and corrected through independent observation and supervisory oversight of the work being done. Weaknesses in plant programs for deciding which jobs require independent oversight or for ensuring that appropriate supervision is available to watch for errors can allow communication errors to occur.

Procedures - Lack of communication skills or failure to apply standard verbal and written communication practices are often associated with communication errors. A lack of training in standard communication techniques and the absence of procedures to prescribe the circumstances in which standard communication techniques will be used often contribute to the occurrence of errors.

17.4 ADDITIONAL RESOURCES ON COMMUNICATIONS

- U.S. Nuclear Regulatory Commission (1996). *Human-system interface design review guideline* (NUREG-0700, Rev. 1, Vol.s 1-3). Washington, DC: U.S. Nuclear Regulatory Commission.

- U.S. Nuclear Regulatory Commission (1997). *Evaluation criteria for communications-related corrective action plans* (NUREG-1545). Washington, DC: U.S. Nuclear Regulatory Commission.

18 COORDINATION AND CONTROL

Note that the structure of this module differs from the others and does not include a section discussing direct causes of errors associated with coordination and control. Errors do not typically result directly from weaknesses in coordination and control at licensee sites. Rather, coordination and control processes, along with other programs, policies and processes, are responsible for establishing and maintaining a licensee's barriers to error. Therefore, in most events, there will be elements of coordination and control processes that failed to prevent the error from occurring. However, the element of coordination and control that failed is typically insufficient to cause the error by itself and so serves as a contributing, rather than direct cause of an error.

18.1 COORDINATION AND CONTROL: SETTING THE STAGE FOR ERRORS

Control can be defined as ensuring that work activities at a site have the intended results and no others. Maintaining control requires that:

- The desired consequences of a work activity are known in advance
- The risks and hazards inherent in the activity are known and addressed
- The external conditions that increase the risks/hazards of the activity are known and can be controlled, and
- The activity is coordinated with other work activities so that they do not interfere with one another and the combination of activities does not create an unexpected plant state.

Operations are controlled at a licensee facility when work activities are routinely conducted without surprises.

There are three elements necessary to maintain operational control:

- Administrative processes that formalize activities commensurate with their risk impact and complexity.
- Effective methods of coordinating the activities of diverse work groups within the organization as well as the activities of individuals within work groups.
- Information management to capture, communicate and retain important information over time and changes in equipment and personnel.

These elements ensure that an organization has the tools required to establish and maintain control over maintenance, engineering and plant operational activities. They are also the hallmark of a reliable organization.

18.1.1 Work Control

The first element of control includes the administrative processes by which work is conceptualized, reviewed, approved, authorized and performed. Licensees have adopted a variety of programs to structure the manner in which work is to be performed. Often the names

and terminology of the processes are different at different sites. However, there are some fundamental characteristics of effective administrative work control processes that should be incorporated into the individual programs.

The control process involves a series of steps that define how work activities in maintenance, engineering and operations are accomplished to ensure that management expectations are met. These steps include:

1. Requirement determination – the decision to perform the activity
2. Development – work design and preparation of the procedures or work package
3. Approval – supervisory review of the work plan
4. Authorization – approval to perform the work after consideration of conditions
5. Implementation – performing the work or activity
6. Oversight – supervisory review of the work or activity including QA/QC
7. Closeout – review of documentation and acceptance of quality of work

Effective work control requires the selection of an appropriate level of formality, deliberateness and precision for each step in the process. The level of formality must be commensurate with the risk, complexity and importance of the activity. Greater degrees of formality ensure higher levels of performance and quality at the cost of additional time and resources. Typically, the greater potential risk, complexity or economic importance of an activity, the greater the formality in planning and implementing the work. For more complex or important jobs, licensee administrative processes may require more extensive reviews of work plans, higher levels of management involved in approving the plans and authorizing the start of work, increased oversight of the work as it is being performed and more thorough testing and evaluation prior to job close-out.

Another significant aspect of operational control is the preplanning that must be accomplished in order to allow simple evolutions to be performed with a reasonable level of effort and to allow rapid and correct action to be taken when off-normal or emergency conditions occur. An example of this preplanning may be observed in the control room when an operator must respond to an annunciator. In this case, plant management has predetermined that the operator can invoke the annunciator response procedure and take the necessary actions without further planning or control steps. The operator has achieved a level of mastery that qualified him or her to respond to the annunciator without further management involvement. The annunciator response procedure has been verified and validated in advance to ensure that the procedure will address the alarm condition. However, each of the seven steps in the control process is still applicable and invoked by management decisions, many of which were made long before the annunciator alarmed and the operator took action to respond to the condition.

Administrative processes are also required to address unanticipated conditions. Even with extensive preplanning, conditions often arise that deviate from those specified or assumed in a work plan when it is implemented. Clear delineation of roles, responsibilities and authorities is necessary for personnel to understand the types of unexpected situations in which they are authorized to make decisions, resolve problems or to change work plans to address existing conditions. Clear assignment of authority to stop work when unexpected conditions arise is also necessary to maintain control. Changes to work plans that have not been analyzed and approved

by individuals who are qualified to evaluate the implications of the changes are a common cause of errors at licensee facilities.

18.1.2 Coordination

Coordination is the process by which resources (people, equipment, tools, procedures, parts, facilities) are identified, scheduled and assigned to a work activity. The scope of work activities may range from station-wide projects (such as steam generator replacements) to individual tasks (such as drafting a work order) and the time frames in which the work occurs may range from minutes to years.

Effective performance requires coordination at two organizational levels. The activities of different organizational units (e.g., maintenance, operations, engineering, and subgroups within those departments) must be coordinated, and the activities of individuals within work groups (e.g., control room or maintenance crews) must be coordinated when more than one individual is assigned to a task. In general, the licensee's managers and work planning and scheduling processes coordinate work activities between organizational units. First-line supervision is typically responsible for coordinating the activities of individuals and teams within a department.

In general, the goals of coordination are to ensure that:

- work activities are planned and scheduled so that they do not interfere with one another
- the combination of activities occurring concurrently does not create unexpected, unknown or unanalyzed conditions
- the necessary resources required to perform a task are available to perform the task when required (e.g., necessary tools, parts and equipment, procedures, sufficient numbers of qualified personnel)
- the work will be completed on time.

Coordination methods range from highly complex, detailed and formalized interactive software planning tools to simple "to do" lists. The licensee will often require the use of several different scheduling tools or methods in station administrative procedures for different types of work activities. For example, most licensees typically use interactive, real time, critical path planning software to coordinate outage work activities. However, they often use less formalized planning and scheduling tools for the daily, at-power operations and other internal departmental activities. In each case, the elements of a successful coordination process are consistent with the complexity and the risk significance of the activity.

Work planning determines the specific human performance elements that are necessary for each work package or job and ensure that they are available and integrated. Human performance elements required to conduct a specific job may include requirements for communication, procedures, skilled personnel, documentation, supervisory oversight, quality assurance, special tools and equipment or other resources.

An example of a coordination error would be a fuel rod placed into the wrong position because the refueling operator did not obtain independent verification of correct grid position prior to lowering the assembly into the core. Clearly, an error of this type could also result from the

operator's inability to select the correct grid position in the core or skipping the step in the procedure that required independent verification. However, if the refueling procedure did not require independent verification of the grid position prior to lowering the assembly, or no one was available to perform the verification even though the operator might otherwise have waited for it to be verified before proceeding, the cause of the error would lie in coordination.

The most common consequences of weaknesses in coordination are that work is delayed. For example, a maintenance crew may have to stop a job for two hours while waiting for a quality control (QC) inspector to be available. Or, work on a piece of equipment cannot start on time because the tags were not hung by the previous shift. Delays typically affect productivity rather than cause errors. However, the likelihood of errors increases if plant conditions change during the delay so that the work plan can no longer be implemented as written, or if the job must be extended over more than one shift and important information is not communicated during shift change.

18.1.3 Information Management

The third element necessary to effective control is the information management systems that capture, communicate and maintain important information that is required to conduct work activities safely. The organization identifies information that will be required to safely and effectively operate or repair the plant, disseminates it and maintains this information to assure that it can be accessed when required. The type of information to be managed includes such diverse areas as operations configuration control of equipment alignments, engineering design control of systems and components, quality assurance of spare parts, and quality control of nondestructive testing. In each case, the information required to safely operate or maintain the equipment must be identified, captured, retained and made readily available as the plant personnel change over time. This process includes configuration management of short-term equipment alignments to ensure compliance with technical specifications as well as long-term engineering design control changes that may impact the plant safety envelope over the life of the reactor.

Identification of important information is a dynamic process. As new conditions and events occur, information requirements will change. For example, industry codes and standards may be updated. Information may become available from Significant Operational Events Reviews (SOERs), licensee reports to the NRC and lessons learned from NRC inspection activities that should be disseminated and retained. Changes in the workforce at a site may also require that more or different types of information be made available to new personnel.

An example of a human error related to information management would be if a vendor determined that a certain preventive maintenance action was required and the plant maintenance staff did not have an active vendor manual program to identify the change and incorporate this preventive maintenance item into the plant's schedule. The result was a component that failed because a process had not been adequately established to update the vendor manuals.

18.2 EFFECTS OF COORDINATION AND CONTROL WEAKNESSES

The following are examples of ways in which coordination and control may set the stage for other performance shaping factors to cause errors.

18.2.1 Work Control

Requirements not identified or incomplete – The risks and hazards associated with the work activity were not identified or were identified incompletely. For example, applicable standards and codes were not reviewed or the job site was not walked down prior to developing the work plan. As a result, controls for the risks/hazards were not incorporated into the work plan.

Work planning informal – The degree of deliberateness, formality and thoroughness in work planning and preparation was not commensurate with the risks/hazards the work entailed. For example, a work package was not developed for the job or was incomplete, resource requirements were not analyzed in advance, or timing requirements were not identified. As a result, the resources required to complete the work on time and safely were not available.

Approval process inadequate – Review and approval of the work plan was weak. For example, personnel not qualified to evaluate it reviewed the work plan, not all of the affected work groups reviewed the plan, or approval was not obtained or was obtained from an individual without the authority to do so. As a result, missing or conflicting elements in the work plan were not identified or risk implications of the work were not identified and addressed.

Authorization inadequate – Authorization to begin the work was not obtained or was obtained on the basis of conditions that had changed or ceased to exist by the time the job started. For example, despite requirements documented in procedures, taught in training and communicated as management expectations, an instrumentation and control technician did not call the control room for permission to power down a controller for testing. Or, a control room operator determined that another emergency operating procedure was applicable to the circumstances and began implementing it without authorization from the unit supervisor.

Implementation not controlled – The work was planned, approved and authorized, but was not performed in accordance with the work plan. For example, individuals without the proper authority changed the plan to accommodate unexpected circumstances.

Oversight inadequate – The amount or type of oversight of the work, including management, supervision or QA/QC, was less than the risks and hazards of the work warranted. As a result, for example, decisions were made without adequate authorization or errors were not caught and corrected.

Closeout inadequate – Documentation of the job was not completed or was completed incorrectly, required tests were not performed, lessons learned were not identified and communicated. As a result, for example, equipment was left in an inoperable condition following maintenance.

18.2.2 Coordination

Job conflicts – Work activities were scheduled in a manner that caused them to interfere with one another. For example, due to schedule slippage, two jobs were scheduled to work on the same component on the same shift.

Job combinations – Work activities that were scheduled concurrently had unanticipated and adverse consequences. For example, a component was taken out of service that operators needed to complete a scheduled tech spec surveillance. Or, all trains of safety system were inadvertently disabled at the same time.

Resources unavailable – The resources required to perform a job were not scheduled to be available when needed. For example, the same health physics technician was assigned to monitor two jobs concurrently on different units. Or, tools and equipment required for a job were in use on another job when needed.

Work untimely – Work activities or work products were not available when needed. For example, new drawings that were required to finish planning a construction job were three weeks late in being delivered from the engineering department.

18.2.3 Information Management

Documentation missing – Required information was not obtained or was not accessible when needed. For example, reference documentation needed to develop a new procedure had not been purchased from the vendor or could not be located.

Documentation inaccurate – Information about equipment, drawings, valve lists, or design basis documents, for example, was out-of-date or wrong. As a result, work packages were incomplete, procedures were incomplete or inaccurate, or training did not address required KSAs.

18.3 ADDITIONAL RESOURCES ON COORDINATION AND CONTROL

- *U.S. Code of Federal Regulations,* Part 50.65, Requirements for monitoring the effectiveness of maintenance at nuclear power plants, Title 10, Energy (revised periodically). Washington, DC: U.S. Government Printing Office.

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Appendix A

Glossary

Glossary of Terms

An **ability** is the combination of knowledge and skill required to perform a task correctly.

An **alarm system** is an automated system consisting of processing and display hardware and software, which processes or analyzes signals from plant sensors and alerts the operator via visual and/or auditory displays when monitored parameters deviate from specified limits (setpoints).

A **barrier** is any means used to protect personnel and equipment from hazards. There are two types: physical and management barriers. Examples of physical barriers are fences, guard rails around moving equipment, protective clothing and safety devices, or shields. Examples of management barriers are risk and hazard analyses, supervision, training, or procedures.

Barrier analysis is a root cause analysis method. It is performed once the basic facts of an event or human performance problem are understood and asks the question, "What physical or management barriers could have prevented this event or problem from occurring?"

A **causal factor** is any action or condition that occurred or existed prior to the initiation of an event and without which the event may not have occurred. The term "causal factor" is synonymous with the term "cause," and may refer to direct, contributing, programmatic or root causes.

Circadian rhythms are also known as "biological clocks" and are patterns in physiological functioning over the course of a day.

Cognitive performance refers to mental activities and includes perception, interpretation, judgment and decision-making.

A **communication error** is a failure in the exchange of information between a sender and receiver, in which the receiver fails to receive or interpret a message consistently with the sender's intended meaning. The failure can occur in creating and sending messages or in receiving and interpreting them.

Communication systems are physical systems that support communications, such as between personnel in the main control room, between the main control room and local sites within the plant, and across sites within the plant. The broad variety of communication media may be generally categorized as speech-based and computer-based systems.

Computer-based procedure system present plant procedures in computer-based, rather than paper-based, formats.

Computerized operator support systems use computer technology to support operators or maintenance personnel in situation assessment and response planning. They can monitor status and provide recommendations or warnings.

A test has **content validity** if the test items are directly related to job performance by ensuring they match the instructional objectives and are appropriately weighted.

A **control** is a mechanism used to regulate, and/or guide the operation of a component, equipment, subsystem, or system.

A **contributing cause** is an action or condition that sets the stage for the event to occur. A contributing cause may be a long-standing condition or a series of prior events that, while unimportant in themselves, increase the probability that the event would occur.

A **corrective action** is an action authorized by and under the control of management intended to solve problems identified as the result of an event investigation. Effective corrective actions for an event prevent the recurrence of the same or a similar event.

A **causal analysis** is a systematic method for evaluating the evidence gathered about an event from an event investigation. The purpose of a causal analysis is to identify the basic set of actions and conditions that, if eliminated or modified, would prevent the same event and similar events from happening again.

A **cursor** is a display graphic that is used to indicate the position of the user's operation on the display (such as an arrow or flashing bar).

A **direct cause of an event** is the actions or conditions immediately preceding the event that caused or allowed it to occur.

The **direct cause of an error** is the actions or conditions immediately preceding the error that caused or allowed the error to occur. Direct causes of errors are also known as **performance-shaping factors**.

A test has **discriminate validity** if it differentiates between workers who have mastered KSAs required to perform the job and those who have not.

A **display** is a specific integrated, organized set of information. A display can include several display formats (such as a system mimic which includes bar charts, trend graphs, and data fields).

A **display device** is the hardware used to present the display to users. Examples include video display units and speakers for system messages.

Display elements are the basic components used to make up display formats, such as abbreviations, labels, icons, symbols, coding, and highlighting.

Display format refers to the general class of information presentation. Examples of general classes are continuous text (such as a procedure display), mimics and piping and instrumentation diagram (P&ID) displays, trend graphs, and flowcharts.

A **display network** is a group of display pages within an information system and their organizational structure.

A **display page** is a defined set of information that is intended to be displayed as a single unit. Typical display pages in a nuclear power plant may combine several different formats on a single VDU screen, such as putting bar charts and digital displays in a graphic P&ID format. Display pages typically have a label and designation within the computer system so operators can assess them as a single display.

Documentary evidence includes paper and electronic information, such as records, reports, procedures, work orders, memoranda, and vendor manuals.

Evidence reliability refers to whether or not different investigators would be able to find the same information and reach the same conclusions from it. Conflicting stories from different interviewees is an example of unreliable evidence that requires further validation.

Evidence validity refers to the accuracy of the information gathered in the course of an investigation. Valid evidence is information gathered from more than one source that supports the "truth" of an assertion.

Functional requirements analysis and allocation is an analysis for identifying the plant's safety functional requirements and ensuring that the functions have been allocated to support an acceptable role for plant personnel.

A **general organizational improvement plan** is developed by plant or corporate senior management and is intended to make significant changes in how work is done and how it is managed in order to improve operational performance and to reverse declining performance trends.

The **Help** function in a software program refers to features that provide guidance to the user (e.g., describes how the user interface works).

HFE program is a plan for ensuring that HFE considerations will be integrated into the development, design, evaluation, and implementation of the HSI.

Housekeeping refers to activities performed to maintain a clean and orderly work environment.

HSI design is the systematic application of HFE principles and criteria to translate the user's function and task requirements into the details of the HSI design. It includes the

use of HFE tests, evaluations, guidelines, and design documentation in the development of the HSI design.

Human errors are inappropriate or inadequate human actions, including failures to take action when required.

Human factors is a body of scientific facts about human characteristics. The term covers all biomedical, psychological, and psychosocial considerations; it includes, but is not limited to, principles and applications in the areas of human factors engineering, personnel selection, training, job performance aids, and human performance evaluation.

Human factors engineering (HFE) is the application of knowledge about human capabilities and limitations to the design of a plant, system, and equipment. HFE ensures that such designs, human tasks, and work environment are compatible with the sensory, perceptual, cognitive, and physical attributes of the personnel who operate, maintain, and support them (See human factors).

A **human performance problem** is a term used to collectively refer to human errors and human performance trends.

A **human performance trend** is a pattern of related errors resulting from the same causal factor(s).

Human reliability analysis is an analysis of the human error mechanisms relevant to the design of the HSI, procedures, staffing, and training to reduce their likelihood and consequences.

Human-system interface (HSI) is the means through which personnel interact with the plant, including the alarms, displays, controls, and job-performance aids. Generically, this also includes maintenance, test, and inspection interfaces.

Impairment refers to decrements in cognitive and physical capabilities that are usually the result of substance abuse, fatigue, illness, stress or other factors that temporarily affect an individual's ability to perform tasks.

Information is organized data that users need to successfully perform their tasks. Information can include (a) a representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or automatic means; and (b) any representations, such as characters or analog quantities, to which meaning is, or might be, assigned.

Integrated system validation entails performance-based evaluations conducted to ensure that the integration of the HSI, procedures, and training adequately supports plant personnel in the safe operation of the plant.

An **intermediate corrective action plan** is more limited in scope than a general organizational improvement plan and focuses on erecting or strengthening barriers to human performance problems.

Investigation methods are the techniques used to gather evidence about an event. Investigation methods include establishing and pursuing lines of inquiry about the event by gathering physical, documentary and testamentary evidence.

A **job and task analysis (JTA)** is the process used to systematically determine the jobs that are assigned to workers and the tasks that must be performed in order to satisfactorily complete the job.

Just-in-time training is training that is provided to workers immediately prior to performing the job.

Knowledge is a set of facts, factual information, a method of analysis or the application of methods and facts to successfully perform a task.

KSAs are the knowledge, skills and abilities required for a job incumbent to safely and competently perform a job.

Labeling and marking refer to the use of labels and demarcations to identify units of equipment, modules, components, and parts.

Learning objectives provide a brief description of the training course material that must be taught by the training program to ensure mastery of all KSAs required to perform a certain job, task or to meet a training requirement.

Limited scope corrective action plans focus on fixing the direct cause of an error. For example, a limited scope corrective action for an ambiguous step in a procedure that confused a worker and caused her to commit an error would be to revise that step in the procedure.

A **local control station (LCS)** is an operator interface related to nuclear power plant process control that is not located in the main control room. This includes multifunction panels, as well as single-function LCSs, such as controls (e.g., valves, switches, and breakers) and displays (e.g., meters) that are operated or consulted during normal, abnormal, or emergency operations.

Maintainability refers to the design of equipment to support effective and efficient maintenance activities.

Managing displays refers to actions performed by a user to control the way that individual displays are presented on a device.

Managing errors refers to actions performed by a user to prevent, detect, or correct errors.

Managing information refers to the capabilities of software that allow the user to create, change, store, and retrieve documents via the computer.

Mastery is the process of achieving the requisite knowledge, skills and abilities to perform a job or task safely and competently.

A **mental lapse** is a momentary gap in recall for the correct knowledge or ability when it is required to perform a job.

National Nuclear Accrediting Board is a body of experts chartered by the Institute of Nuclear Power Operations (INPO) to review, accept and accredit the training programs at every nuclear power station.

An **operating experience review** is a review of relevant operating history from the plant's on-going collection, analysis, and documentation of operating experiences.

Operational validity ensures that test items address the mental and psychomotor activities that are performed on the job.

Performance-based training (PBT), also called the **Systematic Approach to Training**, includes the following five elements:

1. Systematic analysis of the jobs to be performed
2. Learning objectives derived from the analysis, which describe desired performance after training
3. Training design and implementation based on the learning objectives
4. Evaluation of trainee mastery of the objectives during training
5. Evaluation and revision of the training based on the performance of trained personnel in the job setting.

Personal protective equipment (PPE) is equipment worn by a worker to minimize exposure to specific occupational hazards. Examples of PPE are respirators, gloves, aprons, fall protection, and full body suits, as well as head, eye and foot protection.

Physical evidence is matter related to the event, such as equipment, parts, debris, liquids, hardware or tools.

Procedures development refers to the integration of HFE principles and criteria in a procedure development program to ensure that the resulting procedures: (1) support and guide human interaction with plant systems and plant-related events and activities, and (2) are technically accurate, comprehensive, explicit, easy to use, and validated.

A **programmatic cause** is a deficiency in one of the licensee's policies, programs and processes for managing work activities at a site that allows human errors to occur. For

example, a deficiency in a licensee's training program could set the stage for errors because workers may not have the knowledge or required skills to perform a job correctly.

The **root cause** of an event is the actions or set of conditions that, if eliminated or modified, would keep the event from recurring as well as prevent similar events from occurring. A root cause is often responsible for multiple human errors or hardware failures, rather than single problems or faults. Root causes are more fundamental causes than direct causes, and are typically programmatic or management weaknesses.

Root cause analysis is a structured, repeatable, systematic method for synthesizing information about an event and its causal factors to identify the critical set of conditions that, if eliminated or modified, would prevent the same event and similar events from recurring.

Service points are equipment locations used for performing routine maintenance tasks, such as adjusting, cleaning, or replacing components.

A loss of **situational awareness** occurs when a worker has mastered the relevant knowledge, but fails to recognize that the knowledge applies to the task at time of performance.

A **skill** is a motor or mental capability such as the ability to open a valve or operate a controller.

A **soft control** is a control device that has connections with the control or display system mediated by software rather than direct physical connections. As a result, the functions of a soft control may be variable and context-dependent rather than statically defined. Also, the location of a soft control may be virtual (e.g., within the display system structure) rather than spatially dedicated. Soft controls include devices activated from display devices (e.g., buttons and sliders on touch screens), multi-function control devices (e.g., knobs, buttons, keyboard keys, and switches that perform different functions depending upon the current condition of the plant, the control system, or the HSI), and devices activated via voice input.

Span of control refers to the personnel and functions for which a job incumbent has responsibility and authority. Higher management positions within an organization have broader spans of control.

Staffing is the process of accessing, maintaining and scheduling the personnel resources needed to accomplish work under normal and foreseeable off-normal conditions. Staffing decisions consider regulatory requirements, operating costs, the range of expertise required, the number of staff needed and scheduling.

A **staffing analysis** is a systematic analysis of the requirements for the number and qualifications of personnel based on an understanding of task and applicable regulatory requirements.

Stress is a psychological and physiological response to a threatening situation. A threatening situation is one that an individual has appraised as exceeding his or her capabilities to cope. Stressful situations, or **stressors**, may be emotional, cognitive, environmental or physiological.

System response refers to the manner in which the computer system behaves after receiving inputs from the user.

System security refers to features that restrict personnel access to aspects of the computer system to prevent accidental or deliberate damage.

Systematic Approach to Training (SAT) – See performance-based training.

Task analysis is a method of detailing the components of a task in terms of the demands placed upon the human operator, the information required by the operator, the extent to which the task requires reliance on or coordination with other personnel, and the relation of the task to other tasks.

The **task environment** refers to the physical conditions in which work is performed, such a noise and illumination levels, temperature, or radiation.

Task overload occurs when the number of tasks to be performed in a given period of time exceeds the available personnel resources. Task overload may increase stress and often results in the application of various work management strategies. These strategies may include task deferral, delegation or increasing the work pace, all of which may result in errors.

Testamentary evidence includes witness statements and the results of interviews.

Test equipment refers to diagnostic tools used to assess the status of equipment and locate faults that may be present.

Test points are equipment locations used for conducting tests to determine the operational status of equipment and for isolating malfunctions. Test equipment may be connected at these points.

Training development refers to the use of a systematic approach in the development of personnel training.

User-system interaction refers to the set of methods provided in a computer system through which personnel and the computer communicate with each other.

Validation is: (1) The process of determining whether the design of machine elements and the organizational design of human elements of a human-machine system are adequate to support effective integrated performance of established functions. (2) The capability of a system to check information entry items for correct content of format as defined by software logic.

Verification is the process of determining whether procedures, instrumentation, controls, and other equipment meet the specific requirements of the tasks performed by personnel. The term is used in the following contexts:

> **HSI task support verification**: The individual HSI components (e.g., control and display devices) and characteristics (range, accuracy, and safety grade) needed for the task are compared to those actually provided in the work environment.
>
> **HFE design verification**: The characteristics of the HSI, workplace, and HSI support functions are reviewed by the licensee to determine whether their design is consistent with accepted HFE principles, guidelines, and standards.
>
> **Human factors issue resolution verification**: A check to ensure that the HFE issues identified during the design process have been acceptably addressed and resolved.

A **workstation** is the physical console at which a user performs tasks.

Appendix B

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APPENDIX C

BLANK REVIEW TABLES

Table 2.1 Problem Identification and Characterization

Document Identifier:		Problem Number: __		Problem Number: __	
Question Number	**Brief description of the problem and date(s) of occurrence:**				
2.1.1	Was the human performance problem identified?	Yes No NA	Notes:	Yes No NA	Notes:
2.1.2	If not, was the human performance problem tangential to understanding and resolving the issue under review?	Yes No NA		Yes No NA	
2.1.3	Were the individuals involved in the problem identified (by job role)?	Yes No NA		Yes No NA	
2.1.4	Were the actions and decisions or failures to act that comprised the problem described?	Yes No NA		Yes No NA	
2.1.5	Were precursor errors or earlier evidence of a developing trend identified?	Yes No NA		Yes No NA	
2.1.6	Was the problem described in enough detail to support causal analyses and the development of corrective actions?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.2 Investigation Methods

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.2.1	Was the extent of the investigation consistent with the importance of the problem?	Yes No NA	Notes:	Yes No NA	Notes:
2.2.2	Were licensee criteria for determining which issues require an investigation appropriately applied to this problem?	Yes No NA		Yes No NA	
2.2.3	Did the licensee validate the information gathered about the problem by seeking information from more than one source?	Yes No NA		Yes No NA	
2.2.4	Did the licensee seek the appropriate type(s) of evidence for investigating the problem?	Yes No NA		Yes No NA	
2.2.5	Did the licensee gather enough information to understand the sequence of events and conditions leading up to the problem?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.2 Investigation Methods (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.2.6	Did the licensee check plant records to identify other problems that occurred during the same work activity?	Yes No NA	Notes:	Yes No NA	Notes:
2.2.7	Did the licensee identify the programs that applied to the job(s) during which the human performance problem arose?	Yes No NA		Yes No NA	
2.2.8	If the licensee found weaknesses in the applicable programs, were the weaknesses investigated in sufficient detail to understand their scope and likely effects, if not corrected?	Yes No NA		Yes No NA	
2.2.9	Were the licensee's conclusions clearly supported by the results of the investigation?	Yes No NA		Yes No NA	
2.2.10	Was there a basis documented for stopping the investigation?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.3 Causal Analyses

Question Number	Problem description:	Problem number: __		Problem Number: __	
2.3.1	Were causal factors identified for this human performance problem?	Yes No NA	Notes:	Yes No NA	Notes:
2.3.2	Was more than one causal factor identified for the problem?	Yes No NA		Yes No NA	
2.3.3	Was the type of causal analysis of this problem consistent with its importance?	Yes No NA		Yes No NA	
2.3.4	Was there enough information provided to verify the accuracy of the causal factors identified?	Yes No NA		Yes No NA	
2.3.5	Were several possible causes for the problem investigated?	Yes No NA		Yes No NA	
2.3.6	Did the evidence support the licensee's choice of causes?	Yes No NA		Yes No NA	
2.3.7	Were the bases for rejecting possible causes for the problem documented?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.3 Causal Analyses (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.3.8	Did the licensee analyze programmatic weaknesses to determine if they could account for more than one human performance problem?	Yes No NA	Notes:	Yes No NA	Notes:
2.3.9	Did the licensee perform and document a root cause analysis using systematic root cause analysis techniques?	Yes No NA		Yes No NA	
2.3.10	Was more than one root cause analysis technique used?	Yes No NA		Yes No NA	
2.3.11	Was the rationale for terminating the root cause analysis sufficient and documented?	Yes No NA		Yes No NA	
2.3.12	Were the root causes identified under management control?	Yes No NA		Yes No NA	
2.3.13	If corrected, would the causes identified reduce the likelihood of the same and similar problems from happening again?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.4 Corrective Actions

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.4.1	Were corrective actions for the human performance problem identified?	Yes No NA	Notes:	Yes No NA	Notes:
2.4.2	Were the corrective actions effective, or appear likely to be effective, even if no causal analysis was performed and/or documented?	Yes No NA		Yes No NA	
2.4.3	If a causal analysis was performed, were the links between the causal factors and the corrective actions clear?	Yes No NA		Yes No NA	
2.4.4	Was there a corrective action for every causal factor? (a one-to-one correspondence is not required)	Yes No NA		Yes No NA	
2.4.5	Was the scope of the corrective action plan appropriate?	Yes No NA		Yes No NA	
2.4.6	Were the desired condition(s) that the corrective actions are intended to create clearly described?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.4 Corrective Actions (continued)

Question Number	Problem description:	Problem Number: __		Problem Number: __	
2.4.7	Did the licensee define measurable objectives to be achieved from the corrective actions?	Yes No NA	Notes:	Yes No NA	Notes:
2.4.8	Did the licensee define evaluation and acceptance criteria for assessing corrective action effectiveness?	Yes No NA		Yes No NA	
2.4.9	Did the licensee define an implementation process for the corrective actions and specific performance indicators for evaluating success?	Yes No NA		Yes No NA	
2.4.10	Did the licensee assign responsibility to specific, qualified individuals for implementing the corrective actions?	Yes No NA		Yes No NA	
2.4.11	Did the licensee develop a plan for on-going monitoring of continued acceptable performance?	Yes No NA		Yes No NA	
2.4.12	Did the licensee review the corrective actions before implementation to ensure that they will not cause unintended negative consequences?	Yes No NA		Yes No NA	

Notes:

Total number of Yes's: ____

Total number of NA's: ____

Table 2.5 Summary Review Table

A. Number of human performance problems reviewed = ____	Tables			
	2.1 Problem Identification and Characterization	**2.2 Investigation Methods**	**2.3 Causal Analyses**	**2.4 Corrective Actions**
Number of questions in each table	6	10	13	12
B. Multiply the number of questions in each table by the total number of problems reviewed	6 X ___=(B)____	10 X ___=(B)____	13 X ___=(B)____	12 X ___=(B)____
C. Record the total number of Yes answers circled from each table	(C) = ____	(C) = ____	(C) = ____	(C) = ____
D. Record the total number of NA answers circled from each table	(D) = ____	(D) = ____	(D) = ____	(D) = ____
E. Subtract the total in Row D from the total in Row B	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____	(B)____-(D)____=(E)____
F. Divide the answer in Row C by the answer in Row E	(C)____/(E) ____=(F)____	(C)____/(E) ____=(F)____	(C)____/(E)____=(F)____	(C)____/ (E)____=(F)____
G. Multiply the answer in Row F by 100 to obtain the percentage of Yes answers circled in each review table	(F)____X 100 = ____%	(F)____X 100 = ____%	(F)____X 100 = ____%	(F)____X 100 = ____%
Notes:				

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10. SUPPLEMENTARY NOTES

E. A. Trager, I. Schoenfeld, NRC Project Managers

11. ABSTRACT *(200 words or less)*

The Human Performance Evaluation Process (HPEP) is a resource for U.S. Nuclear Regulatory Commission inspectors to use when reviewing licensee problem identification and resolution programs with regard to human performance. Part I provides a step-by-step process for reviewing licensee effectiveness in identifying, analyzing and resolving human performance problems. Part I also addresses the challenges in identifying and investigating human performance problems, describes three root cause analysis techniques, and discusses characteristics of effective corrective action plans. Part II is comprised of the HPEP Cause Tree and Modules. The Cause Tree is a screening tool for identifying the range of possible causes for a human performance problem. The Modules describe frequently identified causes for human performance problems and provide examples. Part II is intended to support the evaluation of licensee root cause analyses for human performance problems identified in Part I.

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